Potential Physical Effects of Any Future 1886 Type Eruption From Tarawera Volcano On The Bay of Plenty Region

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Frontispiece

The 2002 eruption of Mt Etna, Italy

Abstract

Tarawera Volcano is c18 ka, and has experienced 5 eruptive episodes in that time. The last eruption occurred in 1886, dispersing more than 1.3km^3 of ejecta over the Bay of Plenty region, in what was the largest basaltic eruption recognized in the 1.6 Ma history of Taupo Volcanic Zone. Despite Tarawera's violent history, several urban centres are located within a 25km radius of the volcano. These centres, along with more distal towns such as Whakatane and Tauranga will be vulnerable to future basaltic activity at Tarawera.

The 1886 eruption killed over 120 people, and devastated large areas that are now inhabited. Using that eruption as a model of a probable worst-case scenario, potential hazards can be identified that may affect contemporary communities. The vulnerability of the region to these hazards is assessed on both effects of the 1886 eruption and the effects of recent eruptions from other volcanoes on lifelines, infrastructure and agriculture. The 2002 eruption of Mount Etna has also provided an opportunity to closely examine the effects of basaltic volcanism on a modern community.

Several types of infrastructure have been identified as being particularly vulnerable to an 1886 type eruption. These include buildings near the volcano, roads, and electrical distribution networks. Rotorua would be extremely vulnerable during a worst-case scenario, as up to 300mm of tephra could fall on the city. Whakatane's water supply will be likely to fail during an eruption, but more distal areas such as Tauranga will survive without sustaining much damage. Base surges from likely phreatomagmatic activity in the Rotomahana-Waimangu geothermal field may destroy houses, a large section of State Highway 2 and several kilometers of 220kV transmission lines.

Recommendations are presented of measures that will decrease the vulnerability of the region to an 1886 type eruption.

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Chapter 1

Introduction

1.1 Background and Objectives

To the residents of the Bay of Plenty region, Tarawera Volcano is perhaps most famous for having destroyed the renown "Pink and White Terraces" during the 10 June 1886 eruption. An eruption which devastated a large part of the Bay of Plenty region. New Zealand was relatively undeveloped then, little infrastructure existed. Today the same region is intensively cultivated, with many farms and commercial forest plantations. It is home to c 240,000 people, most of whom live in Rotorua, Tauranga or Whakatane (Statistics New Zealand, census 2001). While most of those people will be aware of the destruction of the Pink and White Terraces in 1886, their willingness to live close to the volcano indicates that it would be hard for many of them to imagine an eruption happening again. Yet although quiescent, Tarawera is still an active volcano. An eruption of the magnitude experienced in 1886 would be extremely hazardous to the Bay of Plenty Region. 117 years of development since the last eruption has seen the level of lifelines and infrastructure increase by orders of magnitude. By this same token, the vulnerability of the area has increased as more property has been put at risk. Previous studies have looked at the possible effects of a future large rhyolitic eruption from Okataina Volcanic Centre (e.g. Johnston, 1997; Johnston et al., 2000b, 2002). Only one previous study has attempted to determine some of the effects of basaltic volcanism on the part of the Bay of Plenty region (Johnston & Nairn, 1993). This study offers a more detailed examination of the probable effects of basaltic volcanism on the whole of the region. Thesis objectives are thus:

- To identify possible hazards associated with a future basaltic eruption of Tarawera
- To determine probable effects of those hazards on the Bay of Plenty region, including the identification of vulnerable lifelines and infrastructure.

1.2 Geographical Setting

Tarawera Volcano is located in the Bay of Plenty region, approximately 25 kilometres in a direct line east-south-east of Rotorua. It stands at 1111 m above sea level at it's highest point (Ruawahia dome) (figure 1.1).

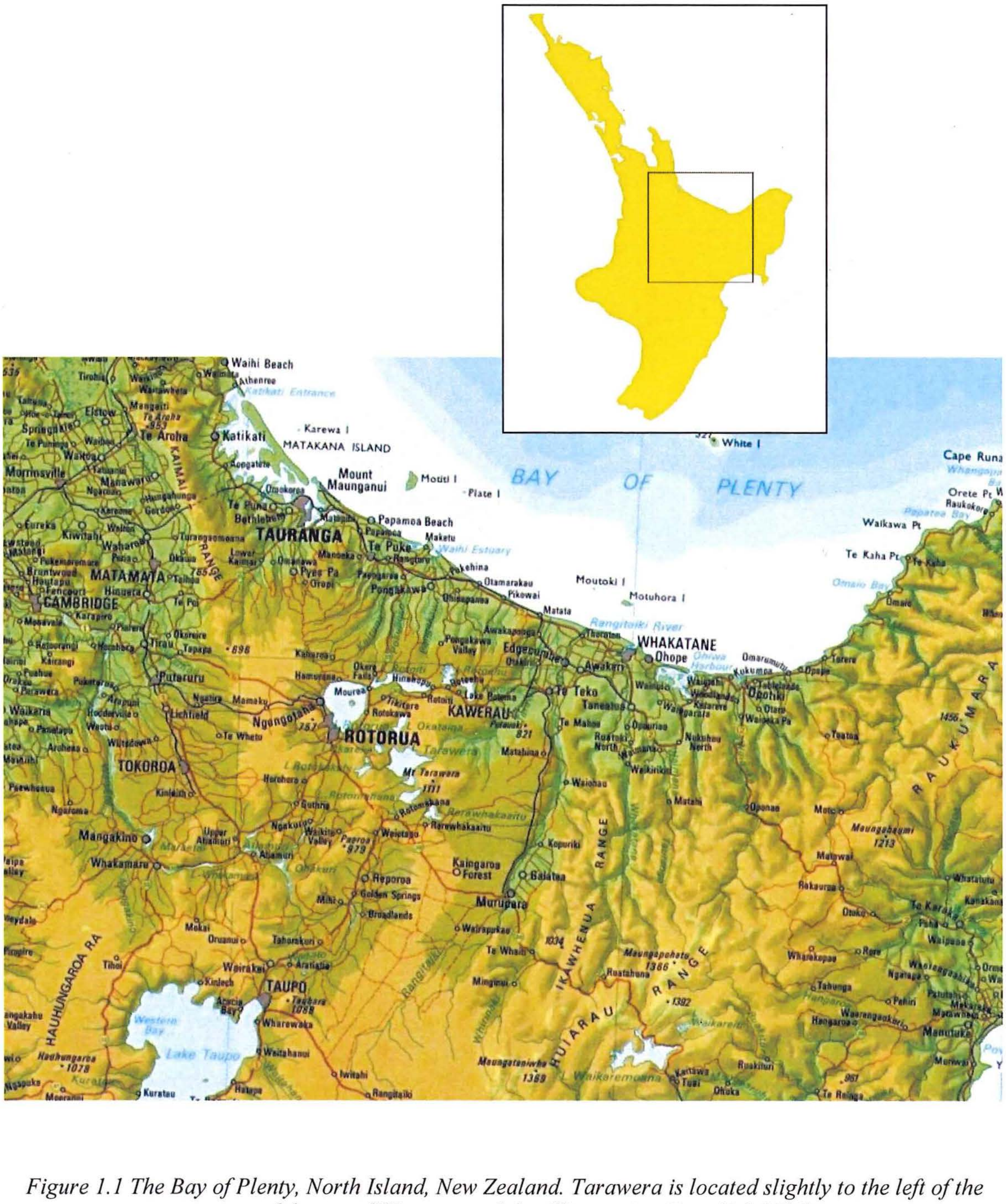


Figure 1.1 The Bay of Plenty, North Island, New Zealand. Tarawera is located slightly to the left of the centre of the map (NZ topomap 1:1 million series, Terralink 2001)

Tarawera Volcano is bounded along its northwest margin by Lake Tarawera. To the north of the mountain are commercial forest plantations managed by Fletcher Challenge Forestry. Similarly forest plantations lie to the west, although some of the land in the immediate vicinity of the volcano is used for farming. Farmland is also to be found to the southwest and south of Tarawera, and around Lake Rotomahana. Rotomahana lies to the immediate southwest of Tarawera, occupying part of the rift that extends from Wahanga dome in the northeast of Tarawera, southwest to Waimangu (figure 1.2).

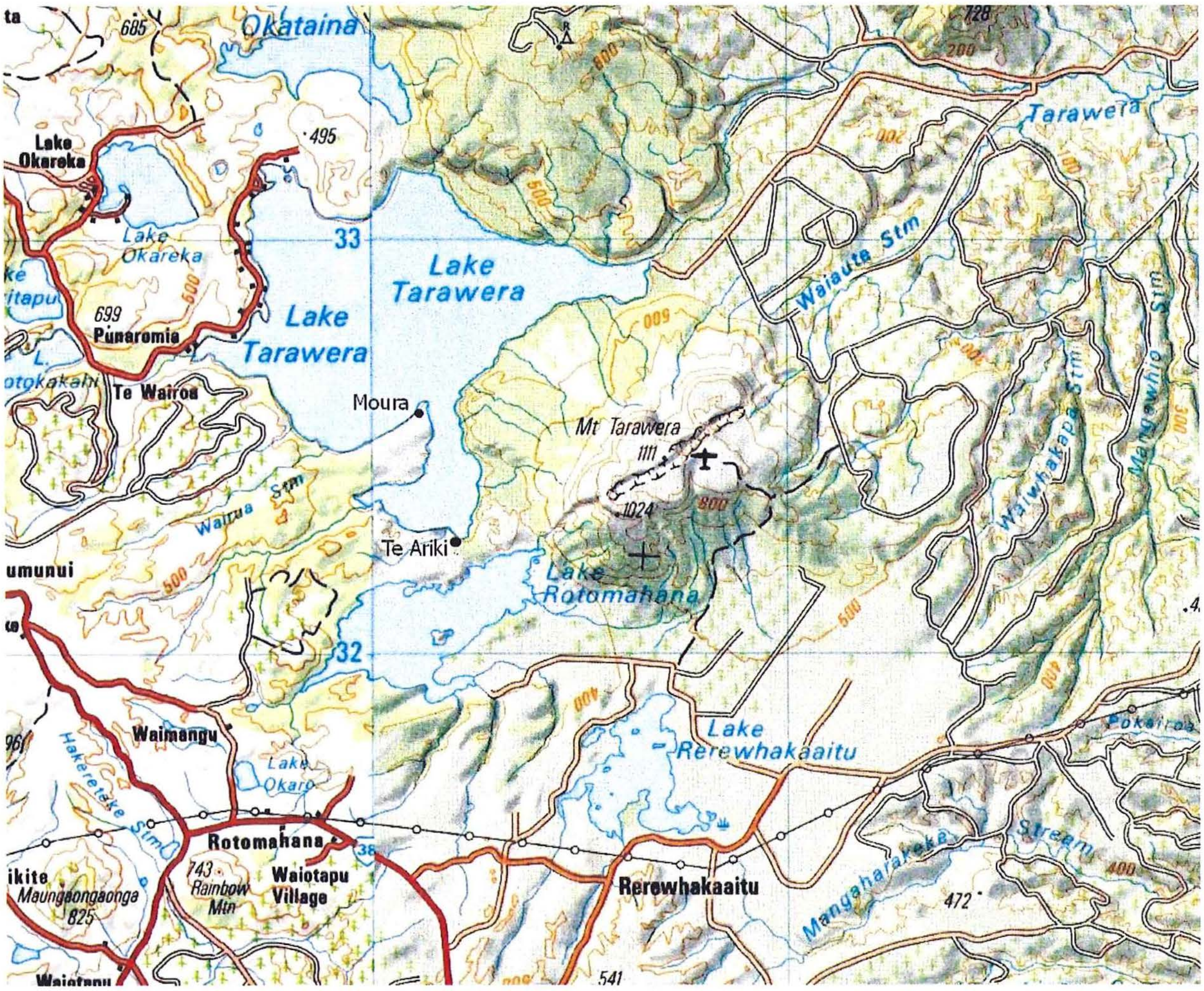


Figure 1.2 The immediate surroundings of Tarawera. Included are the villages of Te Ariki and Moura, destroyed in the 1886 eruption (NZ topomap 1:250,000 (262) series, Terralink 2001)

Land use on the mountain itself is restricted to tourism. However, several farms, forests, lifelines, settlements and towns are close enough to the mountain to be placed at risk in the event of an eruption from Tarawera. These include the towns of Rotorua, Whakatane, Tauranga and Kawerau as well as various smaller settlements. Associated with each of these towns are various services and industries, each of which may be susceptible in different ways. The closest sizeable settlement to the volcano is that of Spencer Road. This road follows the western shore of Lake Tarawera, and has over 600 properties scattered along its length; both holiday homes and permanently occupied dwellings. Similarly Lake Okareka is inhabited by both permanent dwellers and holidaymakers. On the night of the last census (Tuesday 6 March 2001) inhabitants in the Tarawera area – (most of who live in the settlements beside Lakes Okareka and Tarawera) numbered 1581 (Statistics NZ). A further 2820 people were recorded as inhabiting the Tikitere area. Permanent residents within a 10 km radius of Tarawera only number 240, within 20 km this increases to 12000 residents, including Kawerau, (Johnston et al., 2002). The number of people in the lakes region increases dramatically in the summer, due to the influx of holidaymakers. Many of the houses in the area are baches or holiday homes, and camping is popular in several locations in this region. Blue Lake Holiday Park is the nearest sizeable camping ground to Tarawera. The 150 tent/camper/caravan sites and 26 cabins or tourist flats of this park are well patronised in the summer, (HAPNZ, 2002) The Department of Conservation (D.O.C.) administers small campsites on Lake Tarawera at Humphries Bay, Hot Water Beach (these two sites are accessible on foot only) and at the lake outlet. Two more D.O.C. campsites are found beside Lake Rerewhakaaitu, but these sites only cater for a small number of people.

In the greater Bay of Plenty region (defined as the area administered by Environment Bay of Plenty) farmland and plantations of exotic timber cover the bulk of the land area east and north of the Ikawhenua Ranges (which are clad in native bush). As of June 1999, 2020 farms covered a total of 312,140 hectares in the B.O.P. region (Statistics New Zealand agricultural production survey, 1999). The same survey recorded 2595 hectares as horticultural land, and 13564 hectares as exotic timber plantations. Forestry accounts for most of the land use to the south of the Rotorua lakes area down to the south east of Lake Taupo. Eastwards of Tarawera, beyond Rotorua both native bush and forestry plantations cover the Mamaku Plateau. Further farmland exists to the northwest towards Tauranga and Te Puke.

1.3 Geological Setting

Tarawera Volcanic Complex, located within Haroharo Caldera, forms the southern margin of the Okataina Volcanic Centre, (Cole, 1970; Nairn & Cole, 1981). Okataina Volcanic Centre is one of 8 rhyolitic caldera centres that make up part of the Taupo Volcanic Zone (hereafter referred to as TVZ) (Wilson et al., 1995). These caldera centres, along with the andesitic Tongariro volcanic centre, and White Island Volcano (also andesitic) represent the terrestrial manifestation of the Taupo-Hikurangi arc-trench system (Cole, 1990).

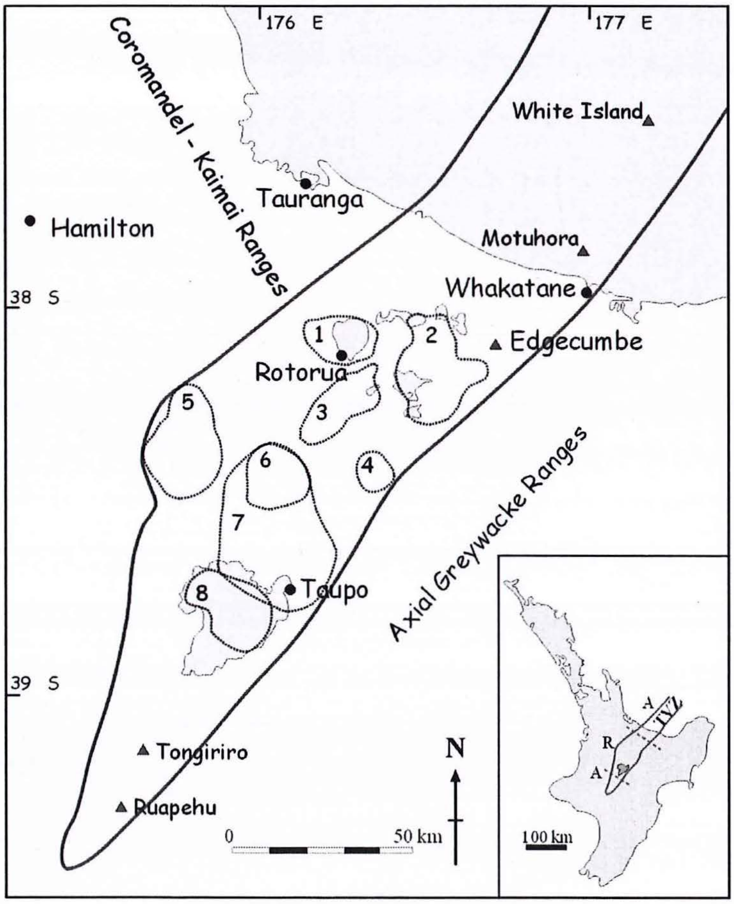


Figure 1.3 Outline of Taupo Volcanic Zone (TVZ) and the structural boundaries of calderas. (1)Rotorua; (2) Okataina; (3) Kapenga; (4) Reporoa; (5) Mangakino; (6) Maroa; (7) Whakamaru (8) Taupo. Inset: North Island of New Zealand and the division of TVZ into segments dominated by andesite-dacite (A) and rhyolite (R) volcanism. Caldera locations after Houghton et al., (1995)

Cole (1990) suggests TVZ can largely be classified as a back-arc basin, the arc itself being represented by Tongariro Volcanic Centre and the andesite-dacite volcanoes of the east side of TVZ, the ensialic basin by the central TVZ. Wilson et al. (1995) argue however that TVZ is a unique type of rifted arc. Yet both of these types of basin are extensional. The splitting or rifting of the volcanic arc is necessary to form back-arc basins; the rifting progresses to become a back-arc spreading centre (Taylor, 1995). Whichever label is applied, the fact remains that TVZ is in a state of extension and crustal thinning. Rifting rates of 7-18 mm a^{-1} have been measured (Walcott, 1987), and crustal thickness is thought to be only 15 km (Wilson et al., 1995). This extension allows for the emplacement of basalts as well as more silicic magmas – more evolved magmas are found in ensialic backarc basins than in those typically found on oceanic crust (Saunders & Tarney, 1984). In the arc itself a spectrum of magma compositions may be erupted. This includes calc-alkaline andesitic to rhyodacitic types, often preceded by island arc tholeiite basalt or basaltic andesite (Hawkins et al., 1984). Similarly, a range of volcanism from basalt to rhyolite is found in TVZ, with rhyolitic rocks making up the bulk of the volume of the deposits (total volume >10,000 km^3) (Cole, 1984; Wilson et al., 1995).

The most recent volcanic activity in TVZ (excluding hydrothermal activity) has been andesitic; at White Island (currently at a low level of activity – scientific alert level one usually) and at Tongariro Volcanic Centre (notably the 1995-1996 Ruapehu eruptions). These centres have also been the loci of activity throughout the 20th century.

The thin crust and extensional environment of TVZ has a high heat flow associated with it, most of which is transferred by geothermal systems. Seventeen such systems are identified as having natural heat outputs of over 20 MW (Bibby et al., 1995). The total crustal heat transfer amounts to c. 2600 MW / 100 km (Hochstein, 1995). This rate of heat transfer is anomalously high, even when compared to other active arcs (Hochstein, 1995). An average modern geothermal heat flux of 700 mW/m3 is measured in TVZ, with a total geothermal output of 4200 ± 400 MW (Bibby et al., 1995). The source of this extremely high heat flux is generally accepted to be the emplacement of magma into the crust (Wilson et al., 1995). Geologically speaking, the crust of TVZ is an extremely active area.

1.4 The evolution of Tarawera Volcanic Complex

Activity began at Tarawera 18ka (the Okareka eruptive episode). This eruptive episode began with a subplinian eruption of basalt scoria, but largely produced rhyolite lavas and pyroclastics (Nairn, 1992). The lavas mark the beginning of the growth of the Tarawera massif. The mountain itself consists of 11 rhyolite domes and flows, and one plug (Cole, 1970). These domes were all extruded during four of Tarawera's five eruptive episodes: the Okareka, Rerewhakaaitu, Waiohau and Kaharoa eruptions (Nairn, 1989). The Rerewhakaaitu and Waiohau are dated at 15 ka and 11ka respectively (Nairn, 1992), the Kaharoa at c. 1305AD (Hogg et al., 2000). Like the Okareka eruption, the Kaharoa eruption included a basaltic component. In fact basalt intrusion of a rhyolite magma chamber is thought to have triggered the Kaharoa eruption (Leonard et al., 2002). It was this eruption that created the prominent domes of Wahanga, Ruawahia and Tarawera that shape the current skyline of the mountain. The Kaharoa eruption also created 5 km^3 of pyroclastic material (Leonard et al., 2002).

The 1886 basaltic eruption differs in that it was the first eruption at Tarawera solely of basaltic material; it did not trigger a rhyolitic eruption. It's duration was only about 4 hours (Cole 1970), but in this time a fissure opened from the northeast end of Tarawera to Waimangu, 17 km to the southeast. From this fissure basalt was erupted during strombolian explosions and fire fountaining. Phreatic and phreatomagmatic explosions took place to the southwest as the rift intersected the geothermal field at Lake Rotomahana. As a result over 1.3 km^3 (Pullar & Birrell, 1973) to 2 km^3 (Walker et al., 1984) of material was erupted, making this the largest basaltic eruption recognised in Taupo Volcanic Zone in the last 1.6 Ma. (Wilson et al., 1995).

All of Tarawera's rhyolitic vents, and the 1886 basaltic fissure strike at 057^{O}N, slightly offset from the 040^{O}N strike of the regional fault pattern, (Nairn & Cole 1981). This vent lineation probably results from a deep-seated crustal fracture, termed by Nairn (1981) the "Tarawera Vent Lineation". It extends from Waimangu in the southwest, 38 km northeast to Mount Edgecumbe (Nairn & Cole 1981). Within the 1886 fissure, individual dikes trend between 073^{O} and 080^{O} (Nairn & Cole, 1981; Cole, 1990). This occurs irrespective of near surface geology, indicating control at depth. The dextral shear indicated by this en echelon pattern mirrors evidence of dextral shear seen elsewhere in Taupo Volcanic Zone, the extension and dextral movement a consequence of the transtensional tectonics of the North Island (Cole, 1990). (Tectonic controls on volcanism are also evident for other basalts in Okataina, Maroa and Taupo calderas). In fact most TVZ basalts occur in lineaments consistent with the NNE regional fault pattern of TVZ (Cole, 1973). The intersections of these faults (e.g. the Paeroa Fault) and the calderas provide areas of weakness for ascending magmas to exploit (Cole 1972).

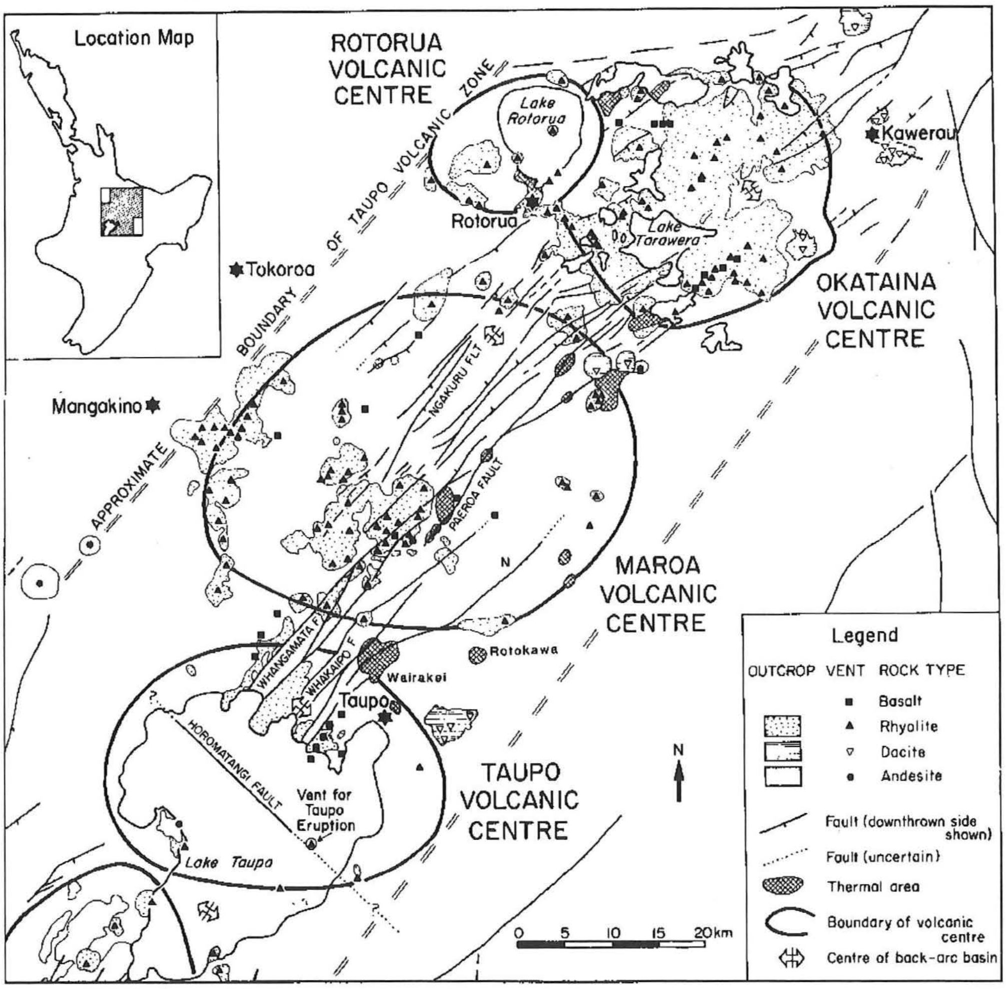


Figure 1.4 Structure and lava types of the Taupo-Rotorua area (Cole 1990). Note the occurrence of lavas along lineaments, indicating tectonic controls on volcanism

1.5 Prognosis for future basaltic volcanic activity in Taupo Volcanic Zone

For hazard mitigation, the likelihood of an eruption, i.e. if and when it might happen, the type of eruption (magma type/source, eruption style), and where it may occur need to be considered. The possibility that future basaltic volcanism will occur somewhere other than Tarawera cannot be discounted. Twenty-one different basaltic deposits have been recognised in the central TVZ (Houghton et al., 1987). The ages of many of these basalts are not well constrained, however none are older than the Late Pleistocene. The ages of those with better age control range from the 290 ka Karangahape basalt (Houghton et al., 1987) to the 3200 year old Rotokawau basalt (Nairn, 1992). Most types of sub-aerial basaltic activity styles are represented by these deposits, as well as phreatomagmatic deposits. The distribution of these deposits through time and space does make prediction of future activity difficult to constrain on the basis of past activity. No particular pattern is observed in regards to the timing of events. Though largely confined to the lineaments consistent with the NNE fault pattern, the abundance of faults in this region makes it difficult to predict where the next basalt may reach the surface. However, the last two occurrences of basalt have occurred at Tarawera - that associated with the rhyolitic Kaharoa eruption of 1305 AD and the 1886 eruption. This fact combined with the fact that the largest known volume of basalt in TVZ is at Tarawera, indicates that it is most likely that Tarawera will be the site of the next basaltic activity in TVZ.

1.6 Prognosis for future basaltic volcanic activity at Tarawera Volcano

The tectonic control of volcanism at Tarawera provides constraints for the location of future volcanic activity in this area. The crustal fracture that has supplied a conduit for magma in the past will continue to do so in the future. Furthermore the amount of basalt at Tarawera has increased with each eruption to date (Leonard et al., 2002). As rifting and crustal thinning progress, it is to be expected that the volume of basalt extruded will increase. It is possible that future activity may occur at any point along this fracture, however the point at which it rises will have a large influence on the style of volcanism to be expected. Whether a rhyolite magma chamber is intersected or not will be the most profound influence on eruption style, but also important is whether water is intersected by ascending magma. This interaction would be unavoidable for a quarter of the length of this fracture, as Lake Rotomahana and the geothermal field at Waimangu are situated along its southwest end. To the north end of the crustal fracture lies the dacitic cone of Mount Edgecumbe. Although small springs are located at the base of this volcano, the level of hydrothermal activity in this area is considerably less than that to the southwest of

Tarawera. The Tarawera - Rotomahana section is the most likely site for a future eruption, given activity along the lineation to date. No extrusion of magma has occurred between the north end of Tarawera and Mt. Edgecumbe. The dikes that fill the fracture here provide another plane of weakness for ascending magma to exploit. An implication of the change from rhyolitic to basaltic activity is that the rhyolitic magma body beneath Tarawera that supplied the previous eruptions has been depleted. This furthers the probability of future eruptions at Tarawera being basaltic (Leonard et al., 2002). The fact that with each successive rhyolite eruption the amount of basalt has significantly increased also indicates a change in style to basaltic volcanism.

While parameters can be identified for constraining the location of a future eruption in the Tarawera area, defining when the next eruption will occur is more problematic. Prior activity has taken place at 18 ka, 15 ka, 11 ka, 1305 AD and in 1886. Intervals between eruptions preserved in the geologic record are thus approximately 3000, 3000, 9700 and 600 years. The lack of any consistent pattern in eruption interval makes determining probable timeframes for future activity almost impossible. However given the potential for disaster resulting from a future eruption, preparedness for such an event is essential.

Chapter 2

A Brief Account of the 1886 Eruption of Mt Tarawera & Effects Thereof

2.1 Precursory activity

On 10 June 1886, New Zealand experienced its first major volcanic eruption since European settlement, its first eruption recorded as having caused death and damaging property. With little prior warning of activity, Tarawera Volcano entered a short-lived but extremely violent eruptive phase. The eruption was completely unexpected. Some unusual phenomena were noted prior to the eruption, but not recognised as being precursors to volcanic activity. After all, Tarawera was not regarded at the time as an active volcano. Contemporary accounts describe occurrences that at the time were unexplained, but subsequent to the eruption took on more significance. These included unusual geothermal activity, earthquakes, and disturbances in Lakes Tarawera and Rotokakahi (Green Lake). S. Percy Smith, the then assistant surveyor-general reported sudden unaccountable rises in Rotokakahi in 1881 and 1883. The 1883 rise was said to be in the order of 4ft (1.2 m), and was accompanied by muddying of the waters of the lake (Smith, 1887). These may not necessarily be connected with the eruption. However, closer to the time of the eruption, on 1 June 1886, an unusual wave, or series of about three waves were seen to cross Lake Tarawera. A renowned local Maori guide of the time, guide Sophia of Te Wairoa, reported seeing the creek near the lakes edge dry, water then came running in, and out again three times (Thomas, 1886). A member of a tourist party that was to venture out on the lake that day, Dr T. S Ralph, also wrote of an inundation of water prior to boarding the boat to cross Tarawera. He noted that the flattened sedges along the lakeshore indicated the wave had been 9 inches to 1 ft in height (22.5-30 cm) (Smith, 1887). He also noted that "The weather was calm, and there was no agitation of the surface of the lake." Local Maori also observed this occurrence (Smith, 1887, p.24-25). Given the timing of these waves, it appears likely they were caused by a submarine debris flow or similar movement; no earthquake was reported as accompanying the waves. Alternatively there is a possibility of a small hydrothermal eruption occurring somewhere within the lake. Keam (1988) suggests this may have happened beneath the Te Tapahoro arm.

Dr Ginders of the NZ Meteorological Service noted earthquakes to have been frequent in the months preceding 10 June. Slight shocks were observed on 26 January, and 30 March, sharper shocks on 22, 28 and 30 April (Ginders, 1886). Comparisons with previous years are difficult to establish however, as the meteorological station (which recorded such events) was only established on 1 January 1886 (Keam, 1988). The Taupo Volcanic Zone as a whole is very active tectonically; earthquakes are not an unusual happening. Newspaper reports from 1886 also describe a few shocks from this period, but fail to mention the early 1886 tremors, inferring that they were nothing significant (Keam, 1988).

Some unusual occurrences in the geothermal system of the region were also noted prior to the eruption. These could perhaps have been more tangibly linked to the eruption than the earthquakes, they represented more of a change from past activity than the seismic activity that was noticed. In early May 1886 an eruption of water being thrown up to "several feet" was said to have taken place in Lake Rotorua (*Evening News & East Coast Business Advisor*, 10 May 1886, p.2, col.4). Later in May a "mud spring" was reported to have erupted in Rotorua, in the middle of the road near the Palace hotel, (at Ohinemutu, on the south shore of the lake). The *Waikato Times* account (29 May, 1886, p.2, col.8) described this eruption as throwing mud up to 120ft (36m) for a short time, while other springs were unusually quiet. However the *Otago Daily Times* reported the same event, and in this account the eruption reached a more plausible 12ft (3.6 m) (*Otago Daily Times*, 16 June 1886, p.5, col.7).

Dr T. S. Ralph ventured to the Pink and White Terraces on the same day that the unusual waves were noted on Lake Tarawera (1 June). His report of that day was reproduced in S. Percy Smith's 1886 account of the eruption (p.24-25). On this visit Dr Ralph observed that mud from one of the geysers had recently been projected 20-25 yards from source (18-22.5 metres), an event that was said to be quite unusual (Smith, 1886).

These events, while unusual were not sufficient to alert anybody to the imminent eruption; earthquakes were neither noticeably more violent nor frequent. Furthermore geothermal anomalies had occurred at other times, and taken alone would certainly not portend that Tarawera was about to erupt. The unusual wave or waves in Lake Tarawera on 1 June may have suggested something unusual was happening, but for anyone to even consider that the mountain was becoming active it would have taken more than this; Tarawera had not been active in centuries.

2.2 A description of the eruption

Accounts of the time of the start of the eruption of Tarawera vary according to the geographical location of the observers. The earliest time of the morning that unusual activity was recorded as occurring at is 1.15am, when the Haszard family of Te Wairoa were woken by an earthquake (*NZ Herald*, 14 June 1886, p.5, col.5). The earthquakes continued, and by 2am a number of the residents of Te Wairoa had noticed "an immense column of smoke... charged with what seemed to be electricity. The edge of the cloud was quivering with flame..." (Blythe, 1886). At a similar time, to the north of Lake Tarawera, and east of Lake Okataina, violent shaking of the ground awaked a party of pigeon shooters, including Alfred Warbrick. Warbrick estimated this as occurring at around 1.40am (earlier than most estimates), whereupon "a terrific roar burst throughout the night" (Warbrick, 1934, p.40-41). The slab hut in which they were encamped was fortunately well constructed. Tremors were violent enough that it was necessary for the men to hold on to the walls to remain standing.

This close to the volcano the earthquakes accompanying the eruption were extremely violent, however their intensity would have decreased markedly over a short distance; in townships further away (e.g. Rotorua, Te Puke) many people were not even woken by the early earthquakes. The amount of shaking experienced varied depending on exact location. Most of those that did notice them described them as slight. For example the surveyor Henry Roche was camping with his survey team at Te Puna-a-Tuhoe, (Kawaha point) and could not at first decide whether the tent poles were moving because of ground movement or wind, deciding after a while he was feeling slight earthquakes (Roche, 1948). Other men in the camp were not even woken. In Rotorua itself, descriptions of the intensity of the earthquakes differed somewhat. This would be partly due to the different perspectives of those describing the earthquakes, but also to the differences in bedrock geology and type of sediments in different areas around the lake. Close to the lakeshore, in Ohinemutu, earthquakes were described by B. F. J. Edwards as having woken him at 1.30am. These were said to have rattled crockery, made doors squeak and set the clock swinging to and fro (Thomas, 1886). Two severe shocks were also described, along with a rumbling noise. Postmaster R. D. Dansey also provided an account of the early hours of the morning of 10 June 1886. He and his wife lived a few hundred metres away from Mr Edwards on the corner of Arawa and Fenton St (Keam, 1988). They described many slight tremors, which gradually grew stronger until the windows of the house rattled. The intervals between the earthquakes lessened until "the whole place was quivering. There was no noise except the constant vibration of the house" (Keam, 1988, p.117). However in Ohinemutu and central Rotorua, the substratum consists of loosely consolidated caldera sediments, whereas the bedrock under the surveyors' camp at Kawaha point is composed of rhyolite lavas (Milner, 2001). Situated upon these loose sediments, both Edward's and the Dansey's houses would be prone to a lot more movement than the surveyors' camp sited upon solid rhyolite bedrock.

Shortly after 2a.m. (Smith, 1887, p.27) reports "2.10 or 2.20", though the exact time varies slightly according to different reports) the rumbling noise heard accompanying earthquakes increased to "a tremendous roar" (Roche, 1948). Anyone left sleeping would have been woken at this time. Tarawera had in no uncertain terms started to erupt. A more violent shake was described by many people at this time. Earthquakes continued throughout the night, however contemporary accounts of the eruption as viewed from Rotorua do not describe these in any detail once the eruption had begun. People were still able to move around without difficulty, and the shaking was not of a large enough magnitude to cause damage to buildings (*Auckland Evening Star*, 16 June, 1886). It is possible that the occasional china plate may have been lost - though even damage on this small scale is not reported (Keam, 1988).

The descriptions of the earthquakes given by residents of Rotorua infer that the intensity of the earthquakes would correspond to about MM4, in some places for short intervals possibly even MM5. The movement at Kawaha point would be less, at MM3 to MM4. This interpretation is based on descriptions of the effects of earthquakes given in the revised NZ 1996 Modified Mercalli Intensity Scale (Dowrick, 1996) (refer appendix 1).

The eruption column was visible from Rotorua, and the summits of Tarawera (Wahanga, Ruawahia and Tarawera) were able to be seen from the survey camp at Kawaha point.

From there a high thin column of black smoke, charged with lightning, was evident over the eastern end of Ruawahia, soon to be accompanied by "showers of red hot scoria and great masses of rock, at white heat… thrown up to about 1500 feet" (450 m) (Roche, 1948). Postmaster R. Dansey described "an immense column of fire… 300 to 400 yards in width… Huge streaks of yellow, red, black and grey ran straight up the column" (Keam, 1988, p.119). Panic ensued amongst much of the populace, causing many inhabitants of Rotorua to flee, either on foot or by horse (Keam, 1988).

Closer to the volcano, Alfred Warbrick and his companions witnessed the eruption from just north of the lake. "It sent up sheets of flaming matter to an enormous height, great quivering masses of fire. The flames went up in quick spasms of expulsion. White-hot ash and stones and debris were hurled far into the sky." (Warbrick, 1934, p.41-42) The slab hut that Warbrick sheltered in, although frighteningly close to the activity, offered an unparalleled vantage point to the eruption of Tarawera. "Wahanga was the first centre of volcanic explosion, then came two distinct points of eruption on Ruawahia… and on Tarawera there also developed a flaming crater… I saw the south end of Tarawera peak split right down and open up, vomiting forth an immense volume of flame" (Warbrick, 1934, p.42-23). Other accounts also describe this sequence of events, as the fissure gradually opened from the Northeast to southwest of the volcano. Within half an hour of the first eruption of magma, by approximately 2.30am, craters along the entire 8 km length of Tarawera were erupting basaltic ash, lapilli, scoria and bombs (Cole & Nairn, 1976). Scoria up to 64 mm in diameter has been found 12 km from the vent source (Walker et al., 1984). Ash and lapilli blanketed a large proportion of the Bay of Plenty region (Cole & Nairn, 1976). The height of the ash cloud was estimated to be approximately 9500m from the top of the mountain, as measured from Gisborne, (Williams, 1886). From Auckland, where the ash cloud was also visible, a height of 14500m above sea level was estimated (Smith, 1886). Walker et al., (1984) calculate a much higher eruption cloud height - almost 28 km for the paroxysmal part of the eruption, based upon estimates of the quantity of material dispersed over the Bay of Plenty during the eruption.

The event was explosive as opposed to effusive, i.e. there were no lava flows. While some observers thought they had seen lava flows, these are supposed to have been welded scoria and bombs from strombolian type activity sliding down the face of the mountain (Cole &

Nairn, 1976). No lava flows are visible today, nor were any seen by S. Percy Smith on his survey of the Tarawera area in July/August 1886 (Smith, 1886). As the eruption continued the centre of activity shifted to the southeast. It had started at Wahanga dome, then an 8 km long fissure opened along the top of the mountain, splitting the domes of Ruawahia and Tarawera. However the fissure did not stop there, craters continued to form to the southeast until the creation of a final explosion crater at present day Waimangu. The total extent of the fissure was 17 km from Wahanga dome to Waimangu (Cole & Nairn, 1976). However the style of eruption was to differ to the southwest of Tarawera Mountain. Lake Rotomahana was situated here, above what was an intensely active geothermal field prior to the eruption. The ascending magma intersected this geothermal field, and consequently interacted with groundwater, causing large phreatomagmatic explosions (Nairn, 1979). The eruptions here were thus much more explosive than those on Tarawera Mountain. Lake Rotomahana, as it then existed, was completely destroyed, the explosions formed a line of craters up to 180 m deep, ejecting 5 x 10^8 m^3 of material in total (Nairn, 1979). Lake sediments (mud and sand) were dispersed over a wide area, burying the villages of Te Ariki, Moura and Te Wairoa (figure 1.2). A large eruption column generated by the eruption reached from 10-13 km high, carrying ash beyond the coast of the Bay of Plenty (Nairn, 1979). Pyroclastic base surges formed, probably from both primary lateral blasts and from collapse of the eruption column, travelling up to 6 km from source (Nairn, 1979). These destroyed or buried everything in their path. Only small amounts of basalt were erupted in these phreatic explosions, however the presence of some large basaltic blocks at Waimangu suggests that it was the interaction of basaltic magma with groundwater that caused these eruptions, as opposed to it being a purely hydrothermal eruption (Nairn, 1979).

The Rotomahana explosions began over an hour after the magmatic eruption of Tarawera, possibly at 3.20am when a large shock was felt (Cole & Nairn, 1976). Hector (1886) indicates the phreatic eruptions began shortly before 4am, however there were no survivors close to Rotomahana to give a more accurate time (Nairn, 1979).

By 5.30 – 6am the paroxysmal stage of the eruption was over, activity at Tarawera had subsided to just steam and gas emissions (Cole 1970; Cole & Nairn 1976). In this short time (3-4 hours) at least 1.3 km^3 of material was erupted from Tarawera and Rotomahana, and dispersed over the surrounding area (Pullar & Birrell, 1973). At Rotomahana and Waimangu, steam emissions continued after the Tarawera eruption subsided - until August 1886 clouds of steam obscured the fissure from view at Rotomahana (Cole & Nairn, 1976). The rift from Rotomahana to Waimangu remained intensely active hydrothermally. Smith (1886) reports that a hydrothermal eruption from Waimangu on 15 June produced a steam column that reached a measured height of 15,400 ft (4620m). His description of the crater of Rotomahana dating from August 1886 is of an intensely active thermal field. "...a dreadful mass of boiling mud, black and brown in colour, with seething pools of steaming water or liquid mud, sometimes cast up into fumaroles ejecting steam, at others vomiting forth stones and mud with a noise like the roar of innumerable steam engines... large bodies of stones, sand and mud... scattered far and wide over the mud covered hills around the margin" (Smith, 1886, p.58). Alfred Warbrick also gives a description of the crater of Rotomahana obtained during a perilous descent into it in July 1886. Hot streams of mud were described as flowing across a fairly firm ground, however his visit was cut short when the main crater burst into life, necessitating his immediate evacuation. Even when he had reached the lip of the crater he and his party reported having to dodge ejecta from the crater, while being showered with finer sand and mud particles (Warbrick, 1934). Waimangu Geyser itself remained active until November 1904, commonly ejecting muddy water and blocks up to heights of 150 m, and occasionally to 460 m (Cole and Nairn, 1976). The region from Tarawera to Waimangu remains a very active thermal area to date.

2.3 Effects of the eruption on the local area & populace

The morning of 10 June 1886 revealed a landscape around Tarawera that was completely changed from the day before. Thick deposits of ash, mud and scoria blanketed the countryside, fissures had opened up, trees were gone, or at the least their foliage was stripped. The villages of Te Ariki and Moura were completely destroyed, not even leaving a trace of their existence (figure 2.1)

Figure 2.1 The site of the village of Te Ariki after the eruption. Photograph by C. Spencer, 27 July, 1886

While many estimates of the number of casualties hover around the 150 mark, the most recent estimate is that about 120 people were killed as a result of the eruption (Lowe et al., 2001). Fortunately the region wasn't very densely populated and the eruption occurred in winter when few tourists were around, or the number of deaths could have been substantially higher.

The eruption ejected over 1.3 km^3 of material, dispersing it over the Bay of Plenty region (Pullar & Birrell, 1973). For most of the duration of the eruption the wind had been blowing to the northeast, as is evidenced by the distribution of eruption ejecta. However the records taken by Dr Ginders at Rotorua's meterological station show that winds during the month of June 1886 were quite variable (Keam, 1988). Should the eruption have occurred a few days earlier or later the results might have been quite different.

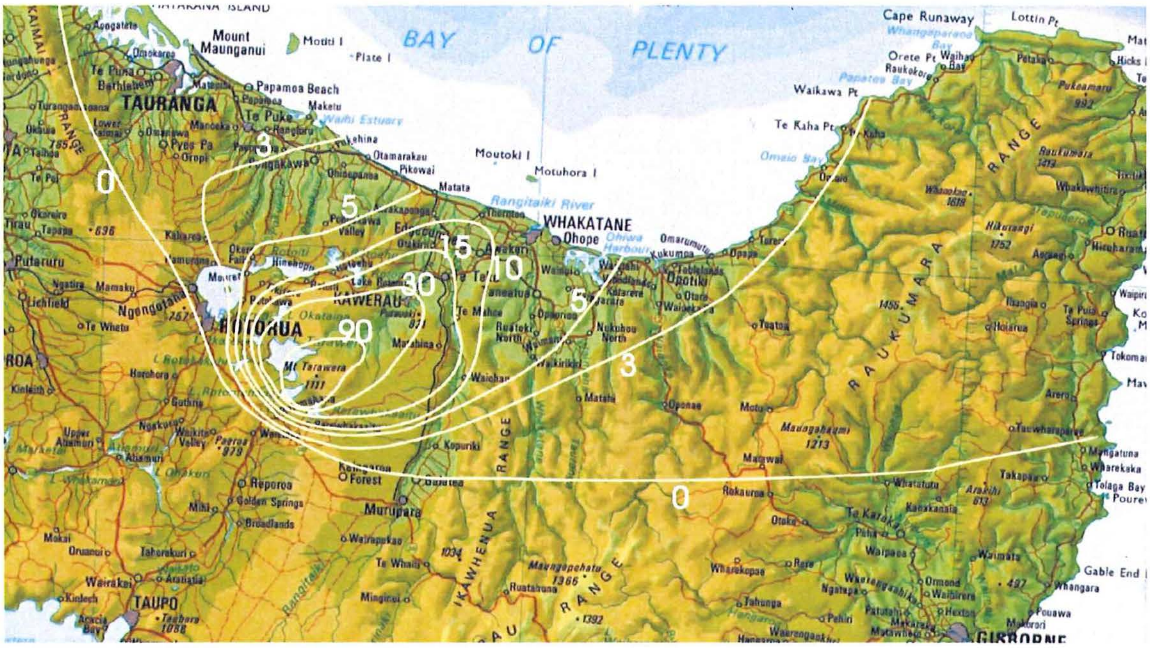


Figure 2.2 Distribution of eruption ejecta over the Bay of Plenty region. After Thomas, 1888. (Isopachs are in centimetres)

Distally, the furthest settlements to be significantly affected by the eruption were those along the coast of the Bay of Plenty, from Tauranga to Opotiki. Along the east coast, significant ashfall was encountered from Tolaga Bay northwards (Keam, 1988).

Tauranga's experience of the eruption was recounted in the *BOP Times,* 12 June 1886. The paper reported that it began between 1 and 2am on the morning of the 10th, when residents noticed vivid flashes of lightning shooting upwards from a dense black cloud in the southern sky. Around 4am a series of "severe" earthquake shocks were felt, but these do not appear to have been severe enough to cause any damage. Rumbling noises were heard also, and by 7am a "leaden cloud" was approaching the city. This ash cloud enveloped Tauranga in darkness, showering the town and surrounding environs in "fine sulphurous dust". S. Percy Smith (1886, p.30) reports this as occurring at 6am, but agrees with the paper as to the depth of the deposit – about half an inch (1.25 cm). The ashfall naturally caused some degree of anxiety. The mayor, R. C. Jordan, after consulting with W. M. Commons of the Northern Steamship Company decided to send a telegram to Auckland requesting steamers in case an evacuation was warranted. Concerned residents were making it clear that they wanted to leave (Keam, 1988). Steamers were made ready, but not required - by 11.30am the ash had settled enough that sunlight was able to penetrate the darkness, (*BOP Times*, 12 June 1886). It was realised that Tauranga was in no immediate danger, and messages began to be received that indicated that the source of the ash was somewhere in the Rotorua-Taupo region (Keam, 1988). The ashfall caused some inconvenience and discomfort to the residents of Tauranga. Shopkeepers who had opened at 9am, though the town was in darkness, were forced to close again due to the influx of volcanic ash into their premises (*BOP Times*, 12 June 1886). In the morning while the ash was falling, goggles and netting to protect the face and eyes were reported to be in great demand (*NZ Herald*, 17 July 1886). "Getting into one's mouth and nose was almost suffocating... Everything is covered with this stuff, it being so very fine the consequence was it worked its way into places where one would imagine it was a matter of impossibility for anything to penetrate, and even things in glass-cases and drawers were smothered with it" (*NZ Herald*, 17 July 1886, p.5, col. 2).

Tauranga was on the periphery of region affected by ashfall. The mean size of ash particles, and of the thickness of ash deposits has been shown to decay exponentially according to distance from source (Pyle, 1989). As it was only the distal part of the ash cloud that affected the town, it was fine ash rather than coarser fragments that reached Tauranga - hence reports of ash being "very fine dust" or "like Portland cement" (*NZ Herald*, 17 July 1886, p.5, col.2). The ash was of nuisance value, and an irritant to breathing whilst falling, but caused little real damage.

Further to the east, Te Puke and Maketu did not fare so well as Tauranga. Te Puke received a deposit of 7.5 cm of ash. Although only 10 km away from Te Puke, Maketu reportedly only received 2.5 cm (Smith, 1886). In the short term this almost proved disastrous for local farmers. The Bay of Plenty was extensively farmed at this time. Tauranga and Whakatane counties combined officially had 72 sheep farmers, and 37196 sheep. Also in the counties were almost 14000 head of cattle, over 2500 horses and 3000 pigs (*Statistics of the colony of NZ for the year 1886*). James Tanner, who farmed 220 acres near Te Puke described the landscape after the volcano as "a mass of ashes" (Tanner, 1886). The immediate view was that all food for livestock was destroyed, Tanner described local farmers driving cattle into the bush so that they may have a chance to survive, it was after all winter and feed was not plentiful. Some farmers had reserves of hay, others tried to drive stock to Tauranga. Some losses were sustained doing this, hungry stock tried to eat the poisonous tutu plant, which survived at the roadside. Carcases of horses and sheep were seen at intervals along the road (*NZ Herald*, 28 June 1886). Further east around Te Teko things were worse, 25 cm of ash and scoria fell on farms here (Keam, 1988). The inhabitants of the town all evacuated, except for the schoolmaster and his wife, who became disorientated and hid under a hawthorn hedge for the duration of the eruption (Keam, 1988). It would take longer for stock to be returned to this area. However for most of the farmers in the Bay of Plenty, the emergency was relieved after a week by rain, which uncovered enough grass for stock to survive (*NZ Herald*, 17 June, 1886, p.6). New growth soon appeared in the spring; damage to pasture was only temporary (Tanner, 1886).

Earthquakes in the Te Puke area were probably similar to those experienced in Tauranga. As in reports from Tauranga, the tremors were described as severe. Tanner described his house as "tottering" during the tremors. Several other reports also describe severe shaking "The house was rocking like a ship on a stormy night" (Swarbrick, 1886, in Keam, 1988, p.108). However other residents in Te Puke, (e.g. Mr Steel, the local schoolteacher) were not even woken by the events of 10 June (Keam, 1988). Damage from shaking does not appear to have occurred, accounts of stronger shocks are presumably exaggerated. This area remained dark until about 10am, when it began to clear. By midday it was "no darker than on an ordinary dull winter day" (Sinclair, 1886).

Whakatane, like Te Puke received a deposit of about 7.5 cm of ash (Smith, 1886). The ash here was coarser than that encountered further west in Tauranga, the bottom 5 cm were described in the *NZ Herald* (15 June 1886, p.6) as "heavy coarse dark sand". The upper 2.5 cm was a lighter colour. This would represent the later part of the eruption - the Rotomahana phreatic eruption. Earthquakes were also frequently felt, but were not very strong (Keam, 1988). Opotiki received about half of the amount of ash that Whakatane received (Smith, 1886).

Gisborne did not receive any ash, however the ash cloud passed over the town, and the explosions of the eruption were heard (Williams, 1886).

Given its proximity to the eruption, Rotorua was very fortunate to have escaped being heavily damaged or even destroyed. As it was only a light dusting of ash fell on Rotorua – less than 1 cm (Smith, 1886). Rotorua did experience unusual hydrothermal activity during the eruption though. Reports vary somewhat - there are some exaggerated accounts which describe events third-hand. However existing mud pools and springs were described as becoming more active (Keam, 1988). In this same account a spring on Rangiruru St. was said by Postmaster Dansey to have begun spouting water to 50 ft (15 m). This height may or may not be accurate, but the outbreak of the spring or vent as a geyser was heard and then seen by some of the sanatorium employees who were approaching it (*NZ Herald,* 15 June 1886). Several accounts exist describing other new hydrothermal vents or springs that appeared during the morning of 10 June (Keam, 1988).

The combination of earthquakes, hydrothermal eruptions and the spectacle of the volcano itself was enough cause panic amongst some of the residents of Rotorua and Ohinemutu. Some fled their houses "In the inky atmosphere, rapidly flitting forms were encountered as they fled forth in scanty apparel" (Black, 1913, p.17). Some thought the day of Judgement had come (*NZ Herald*, 15 June 1886). Arthur Burrows, resident in Rotorua saw the geysers at sulphur point in action, and the glow of the volcano beyond them, but attributed the glow to the thermal activity at sulphur point (Keam, 1988). This caused him to run through the main street crying out "Sulphur Point has blown up, Rotorua is sinking!" (Keam, 1988, p.123). The *NZ Herald*, on 11 June (p.6) reported that "Many left their houses in their nightdresses and (with) shawls around them only, carrying their babies and young children, running with one aim to flee from this devouring element, which was expected every moment to engulf the entire community, so great was the terror of the people." Some fled to Ngongotaha, others carried on heading for Tauranga or Cambridge (Keam, 1988). Henry Roche observed many of these people fleeing past the survey camp at Kawaha point. He recalled one group that shouted, "It's the end of the world, we're going." Though they did not reply to his question of "where to?" (Roche, 1948). Many stopped at Te Awahou, (12 km from Rotorua) prompted by the cold and wet and exhaustion to stay at the schoolhouse where the local schoolmaster put on a fire to warm around 50 refugees who arrived in the night and early morning (Roche, 1948).

Although the eruption caused some to panic in Rotorua, effects in the town were not the catastrophe these residents expected. For those living closer to the volcano however, the effects of the eruption would be devastating. In the immediate vicinity of Tarawera and Rotomahana, several Maori settlements existed. On the shores of Lake Tarawera were Te Ariki and Moura, on the edge of lake Rotomakariri was the small settlement of Waingongongo. All of these would be utterly destroyed, all residents killed. Te Wairoa, approximately 1 km to the SE of Lake Tarawera would also suffer badly, though most people in this location survived.

Due to the logistics of procuring boats, and then getting them from Rotorua to Lake Tarawera through mud, ash and fallen trees, a rescue party sent to Moura and Te Ariki was not able to start the search for survivors until 14 June. The journey to Wairoa, and thence to the lakeside where the boats were to be launched was no easy task. Draught horses were used to pull a 24 ft (7.2 m) whaleboat and a 16 ft (4.8 m) skiff (Warbrick, 1934). They had to contend with not only the mud and ash, but also fallen trees around lake Tikitapu. These needed to be either removed, or the boats had to be jacked over them (Warbrick, 1934). In places the party had to bodily lift the whole wagon over the fallen trees (*NZ Herald*, 17 June 1886, p.5). A boat was necessary - reaching these places overland would be even more difficult, especially if one was attempting to carry injured survivors back. Joseph and Arthur Warbrick, along with a man known as Kean tried to reach Te Ariki overland from Te Wairoa on the 12th, but could not get there before nightfall, and had to return. A second attempt on the 13th by Warbrick and C. H. Humphries reportedly reached the northern side of Rotomahana, just above the site of Te Ariki. Humphries described the site as "a mass of liquid mud" (*The Press*, 15 June 1886, p.3). The unstable nature of the mud and ash deposits was seen by the rescue party in the boats during the trip around the southern shore of the lake; several large slips of mud occurred at this time, sliding from the top and sides of the hills into the lake (Harrow, 1886). At the site of the village of Moura, nothing was left but very liquid mud, those who attempted to land there sank about 3 ft (90 cm) into it (Keam, 1988). Trees that were growing there were found floating in the lake about a mile offshore (Keam, 1988). A scene of devastation again greeted the rescuers at Te Ariki (figure 2.1). This village was only 1.5 km north of the Rotomahana craters. Again nothing was left to indicate it had ever been there, where it had been was now a bank of mud, estimated to be anything between 25 feet (7.5 metres) (Mair, 1886; Edwards, 1886) and 50 feet (15 metres) thick (Harrow, 1886). Later examination of these deposits shows them to contain cross-laminated primary bed forms – indicating that the village was buried by surge flows (Nairn, 1979). Even had the rescue party arrived earlier, there would have been no chance of survival. Where the village of Waingongongo had been was now a large explosion crater, leaving little doubt as to the fate of the Ngati Rangitihi inhabitants (Keam, 1988). A similar fate befell Rangihuea, the Te Ariki Chief and colleagues at Rotomahana itself, possibly on Puai Island (*NZ Herald*, 25 June 1886, p.6) or beside the Pink Terraces (Keam, 1988). No trace was ever found of bodies from these locations.

Te Wairoa

Figure 2.3 Tephra at Te Wairoa, local resident "Rewiri" and his whare. Photograph by A. Ryan, 13 June, 1886.

Further away from the craters of Rotomahana and the fissure of Tarawera itself, the village of Te Wairoa was close enough to receive a heavy deposit of ash and mud, but far enough that there were survivors. S. Percy Smith, surveying the district a few days after the eruption (from 13 to 16 June) measured the depth of the deposit of ash, scoria and mud at Wairoa, finding it to be 2 ft 8 inches (80 cm) deep. In some places it had drifted up against fences or trees etc to an estimated depth of 5 to 7 ft (1.5-2.1 m) (Pond & Smith, 1887). In

Early July Professors Brown and Thomas, of Auckland University also measured the depth of the deposit at Te Wairoa, coming up with results of 2 ft 3 inches and 2 ft 10 inches, ~68 cm and 85 cm respectively (Keam, 1988).

Scoria and ash began to fall sometime after the beginning of the eruption, long enough that Joseph McRae (the proprietor of the Rotomahana hotel) and about 12 observers from Te Wairoa) had a chance to get up, walk to the church at Te Mu, view the spectacle of the eruption for at least ten minutes, (Humphries, 1886) and then return to the Terrace Hotel (McRae, 1886). Five minutes or so later ash and scoria began to rain down upon the roof (Humphries, 1886). Clara Haszard, daughter of the local schoolteachers described stones clattering on the roof from about 3am. "The noise was so great we could not hear each other speak…" (Haszard, 1886). Both iron roofed wooden buildings of the European settlers and Maori whares were situated in this village. The accumulation of material upon these buildings proved too much for most of them to sustain, those that did survive were generally propped up with timbers by the occupants in an effort to keep the roof from collapsing. Maori whares tended to fare better under the weight of the ash, partly due to the steeper pitch of the roofs, but also because of the strong ridgepoles used in their construction. Even these required additional reinforcement in some instances. The roof of the large whare of Guide Sophia was reported to have begun to sag, before being propped up (Keam, 1988). Fortunately this held, as it sheltered many of Te Wairoa's inhabitants from the ash, scoria and mud. Some of the ash was said to have slid off owing to the steepness of the roof (Keam, 1988). The wharepuni (principal building) "Hinemihi" was successfully propped up in a similar fashion, using wooden benches to support the roof (*The Press*, 16 June 1886, p.3). Like some of the colonial buildings it had a wooden tile roof, but in this case stood up to the bombardment of volcanic ejecta.

Most of the buildings of the European settlers were roofed with had corrugated iron, some with wooden tiles. The roofs of the buildings not only collapsed under the weight of the ash, but were also penetrated by some of the larger scoria clasts. The Haszards, local schoolteachers, had "stones" break through the roof and lodge in the ceiling and walls of their house (Lundius, 1935; Haszard, 1886). Later in the night the roof collapsed, a falling beam striking and killing Charles Haszard (A. Haszard, 1912). Five members of this family were killed by the eruption, the ash and mud burying them alive (Keam, 1988). Volcanic ejecta was also reported to have broken windows in the Rotomahana Hotel (Humphries, 1886). This can be seen in photographs taken on the 13 June, 3 days after the eruption (Keam, 1988).

Figure 2.4. The ruins of the Rotomahana hotel, 13 June 1886. Photograph by A. Ryan

The roof and verandah of this hotel were both to fail due to the accumulation of material, the collapse of the latter killing English tourist Edwin Bainbridge (Keam, 1988). Before the collapse of the main part of the roof of the hotel, the detached kitchen and pantry had already collapsed, as had the bar (McRae, 1886a).

Contemporary photographs of Te Wairoa show thick accumulations of ash and mud covering everything, those roofs that remain have accumulations of up to ~ 40 cm of ash upon them. In the case of the hen-house in figure 2.5, the survival of the shed is due to the fact that the roof was shored up. This was performed by H. Lundius as he sheltered here with J. C. Blythe and Clara Haszard after the house of the Haszard family collapsed (Keam, 1988). More ash may have accumulated on some roofs, however by the time that photographs were taken it is possible that some ash may have either fallen off or been blown off the roofs. Steeper roofs naturally had less ash accumulate on them, though even these did not always survive. The church at Te Mu, overlooking Te Wairoa, was one such

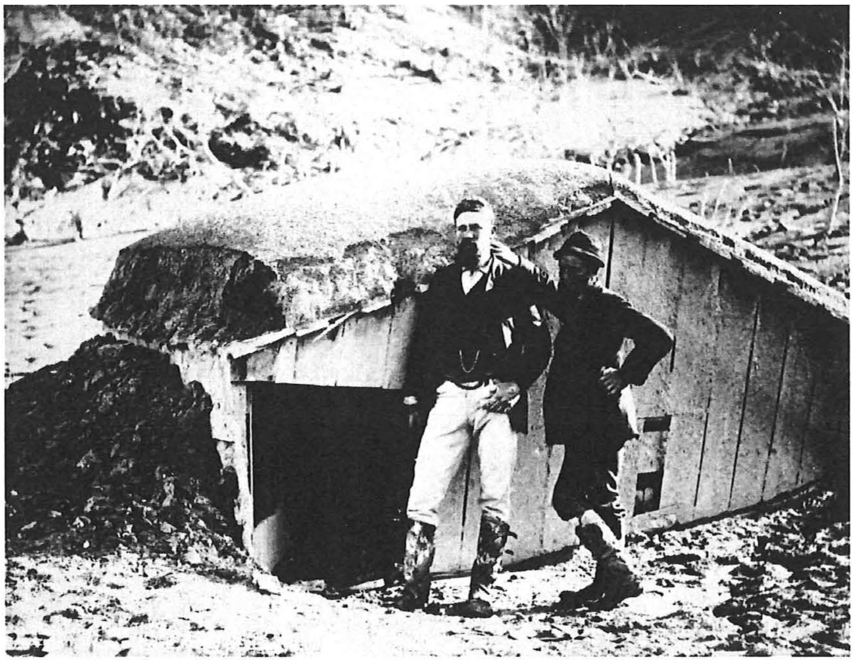


Figure 2.5 Tephra accumulation on the Haszard family hen-house. Photograph by C. Spencer, 8 July, 1886

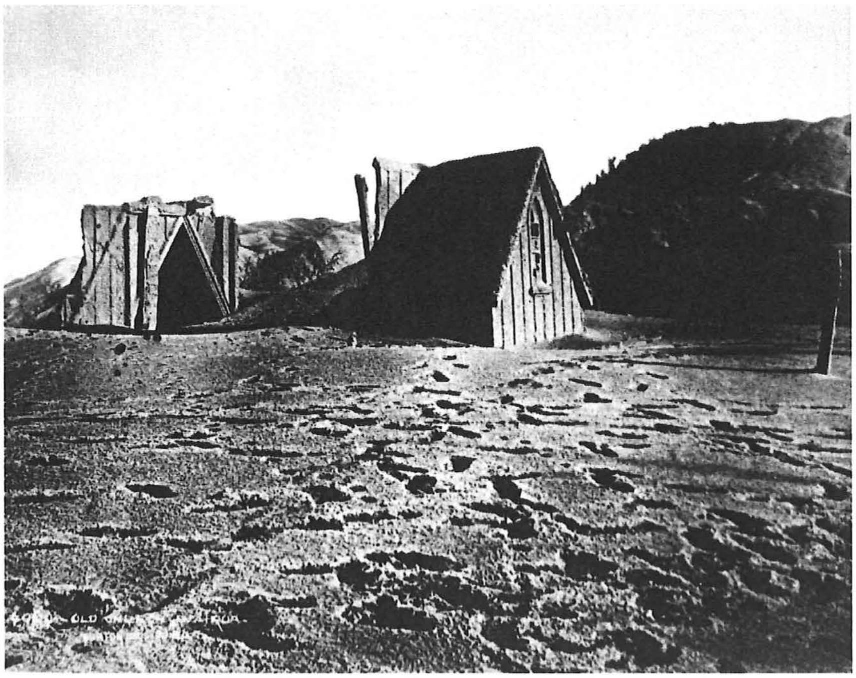


Figure 2.6 The remains of the Church at Te Mu. Photograph by A. Ryan, 13 June, 1886

example – although the ash was more prone to sliding off the steeper roof, the thickness of the ash here (the photograph shows drifts of over two metres) sufficed to collapse the roof and destroy the church (figure 2.6).

Also on slightly higher more exposed ground than Te Wairoa itself was the settlement of Tokiniho. This was situated on a hill above the west shore of Lake Tarawera, about 3 km north of Wairoa (Keam, 1988). This would place it in the vicinity of the present day Spencer Road settlement. A search party that reached it found a collapsed whare, and about 10 bodies inside (*NZ Herald,* 14 July 1886, p.5). There were no survivors (Keam, 1988).

Trees in the Wairoa Township were stripped of all foliage by the falling debris, but largely remained standing. This was not the case for much of Tikitapu bush, around the road between Lake Tikitapu (Blue Lake) and the crest of the hill before Rotorua. In this region the road ran (and still runs) through the bottom of a valley bearing S.E., the direction from which a storm was blowing during the night of the eruption, and also the direction of Rotomahana. While this area was beyond the extent of lateral surges from Rotomahana (Nairn, 1979), the combination of wind and the weight of mud carried by that wind served to fell many trees in the bush at this locality. In the base of the valley trees were largely felled parallel to the road, those remaining had the Southeast sides of their trunks coated in mud (Pond & Smith, 1887). The resulting blockage of the road served to hamper both evacuation and rescue efforts. The road was impenetrable for horse drawn carriages etc, at least for those without the manpower of the rescue party sent through on 13 June. Buggies etc were abandoned at the start of the bush, people and horses were able to make it through (Roche, 1886). Even then it proved difficult, Dr James Hectors party journeyed from Rotorua to Te Wairoa on 13 June. Realising how unstable the Rotomahana mud that draped the landscape was, Hector advised an evacuation of Wairoa – if it rained it would become even more difficult to get through (Keam, 1988). Nevertheless it was with great difficulty that they made their way out to Rotorua the next day. "Every few yards men had to stop and breathe. The mud on their boots weighed several pounds. Mr Pope, the Inspector of Native schools, got into a place from which he was unable to extricate himself, and it was necessary to get a man to go in with a horse to pull him out." (*NZ Herald*, 15 June 1886, p.5). This occurred in the flat area next to Lake Tikitapu. The settlement in this area was also heavily damaged by the eruption. Travelling to Wairoa on

10 June surveyor H. Roche estimated the mud on the road to be 1½ ft deep (45 cm) (Keam, 1988). It was certainly enough to destroy the sawyers' cottages. In addition, slips coming down off the hills would cause further obstacles for those trying leave or reach Wairoa. Although were trees felled here partly because of the strong winds on the night of the eruption, the falling mud, ash and scoria served to strip almost all foliage off plants and trees from Tikitapu bush to Tarawera. This fact was noted by many observers at the time.

Effects on Lifelines

While infrastructure in terms of lifelines was obviously much less established than today, telegraph wires did exist in the region. Limited telephonic communications were also available, but only within major towns or for short distances (Keam, 1988). Telegraphic communication was thus the most usual and effective means of communication. Ashfall from the eruption brought down the lines between Rotorua and Maketu, poles were downed in quite a few places. A lineman from Rotorua estimated that each pole was supporting 50 pounds of mud (~23 kg), and described the lines as being "as thick as a candle with mud" (*NZ Herald*, 14 June 1886). This left Rotorua direct communication with Taupo and Napier, though retransmission from Napier was still possible (Keam, 1988). Rotorua was thus able to communicate with the outside world after the eruption – although there is no question the outside world knew of the eruption, given that the eruption column was seen from Auckland, and the explosions heard from Christchurch! (*Christchurch Star*, 11 June 1886, p.3).

Although many of the lines survived, they became temporarily unworkable during the eruption. This was noted to have occurred from 5.50am until 9.50am at the exchange in Maketu. The telegraphist attributed this to be due to the electrical disturbance that accompanied the eruption (Smith, 1886). Similarly, shortly after the commencement of the eruption, the telegraphist and postmaster at Rotorua, (Roger Dansey) found strong electric currents did not allow transmission of messages. He was unable to get through to anywhere until contacting Napier at 8am on the morning of the 10th (Dansey, 1886). Lightning strikes associated with the electrical disturbances caused by the eruption also caused damage to telegraph lines between Maketu and Opotiki, temporarily cutting this link (*Auckland Evening Star*, 15 June 1886, p.2).

The only other lifelines present in the region were roads – railways did not yet exist in the central or eastern Bay of Plenty, the closest lines were at Cambridge and Oxford (Tirau) (Keam, 1988). The road between Te Wairoa and Rotorua was one of the worst affected, difficulties experienced by travellers on this route immediately after the eruption have already been described. However sediment movement would also cause problems days and weeks after the eruption. On 14 June a landslide of mud and volcanic debris came down from the steep hills above the North end of Tikitapu and blocked the road to all wheeled traffic (*NZ Herald*, 18 June 1886, p.6).

This route experienced further problems in mid July, with subsidence occurring between Tikitapu and the ridge before Rotorua. This took place on a dramatic scale, contemporary photographs and drawings illustrating gaping fissures opening across the road.

Figure 2.7: Subsidence on the Te Wairoa Road. Photograph by J.C. Blythe, July, 1886

One of these fissures was estimated by S. Percy Smith (1887) to be about 90 ft deep (27 m), a figure which appears accurate given the scale of the figure seen on its edge in figure

2.7. Fault movement during the eruption caused the formation of these subterranean crevices. Sediment movement within these could occur quite gradually, allowing the surface to appear undisturbed. However water from winter rains would rapidly exacerbate this, until eventually the surface above the fracture would catastrophically fail, exposing the deep fissures underneath. Similar fissures were seen to have opened in the region to the Southwest of Tarawera, from Waikorua (Earthquake Flat) to Maungakakaramea (Rainbow mountain) (Smith, 1886). This area is intensely faulted, and still actively subsiding, owing to the general extension and stretching of the earth's crust in Taupo Volcanic Zone (Cole, 1990).

Post-Eruption Lake Level Changes

Changes in lake level due to sediment movement occurred after the eruption in Lakes Rotorua, Rotokakahi and most notably, Tarawera. Lake Rotorua appeared to have risen about 15 inches (37.5 cm) relative to the shoreline on the morning of 10 June (*NZ Herald*, 14 June 1886, p.5). However subsequent investigation showed this to be partly due to localised subsidence around the shoreline (Keam, 1988). The deposition of ash and mud into the lake would also account for a rise in lake level. Lake Rotokakahi (Green Lake) also experienced a rise in lake level after the eruption, but the rise here was due to the outlet of the lake being blocked by mud (*NZ Herald*, 19 June 1886, p.6). The Ngati Tu hapu living at Kaiteriria on the south corner of the lake had to abandon their village as the rising lake gradually engulfed it (Keam, 1988). It wasn't until almost a year later that the mud barrier was overtopped, and the lake drained a little (*NZ Herald*, 15 June 1887, p.6).

The level of Lake Tarawera gradually rose over the years following the eruption, as the outlet became choked with debris, indirectly caused by the eruption. By 1904, the lake had risen 12m from its pre-eruption level (White et al., 1997). The collapse of a tephra bank on 1 November led to flash floods that inundated an area of 150 km^2 (White et al., 1997). This dam was located about 1 km downstream of the current outlet, at the mouth of a tributary gulley that extends from the Tapahoro lava flows about 5 km north (Hodgson & Nairn, 2000). It was possibly a fan deposited from both older rhyolitic material and 1886 scoria carried down this tributary that caused the dam that blocked the outlet of the lake

(Hodgson & Nairn, 2000). In three days the lake fell 3.3 m, at times ~700 $m^3\ s^{-1}$ of water was being discharged from the lake (Maclaren, 1906). At Kawerau, peak flow in the Tarawera River has been estimated to have been 800 $m^3\ s^{-1}$, compared to a normal present day average flow of 20 $m^3\ s^{-1}$ (Hodgson & Nairn, 2000). The deposition of material carried downstream in the flood caused intense aggradation of the Tarawera riverbed, resulting in the river avulsing across the plains and causing further flooding problems.

This event can be regarded as the last major physical effect of the 1886 eruption. It is interesting to note that the ash and scoria deposit has not undergone any substantial rilling or surface erosion since deposition. White et al., (1997) attribute this to the high permeability of the tephra deposit and gentle relief of the area. This is in sharp contrast to erosion of the Rotomahana mud deposit following the eruption. Rapid growth of plants in the spring following the eruption also helped consolidate the deposits of the 1886 eruption. The area now is clothed in lush native bush, forestry plantations and farms. 117 years after the eruption there is little visible in the natural environment to remind one of the events of 10 June 1886.

Chapter 3

Basaltic volcanic hazards generated by Mount Etna, Italy: effects of the 2002 eruption on the province of Catania

3.1 Background

Mount Etna is Europe's largest volcano, and one of the most frequently active (after Stromboli). The volcano is situated within the province of Catania, on the east coast of Sicily. This province is home to almost 1,100,000 people, all of whom are susceptible to hazards created by the volcanic activity of this mountain. Of these 1,100,000 inhabitants about 350,000 live at the base of Etna, in the city of Catania. Many smaller towns are situated further up Etna, closer to the active vents.

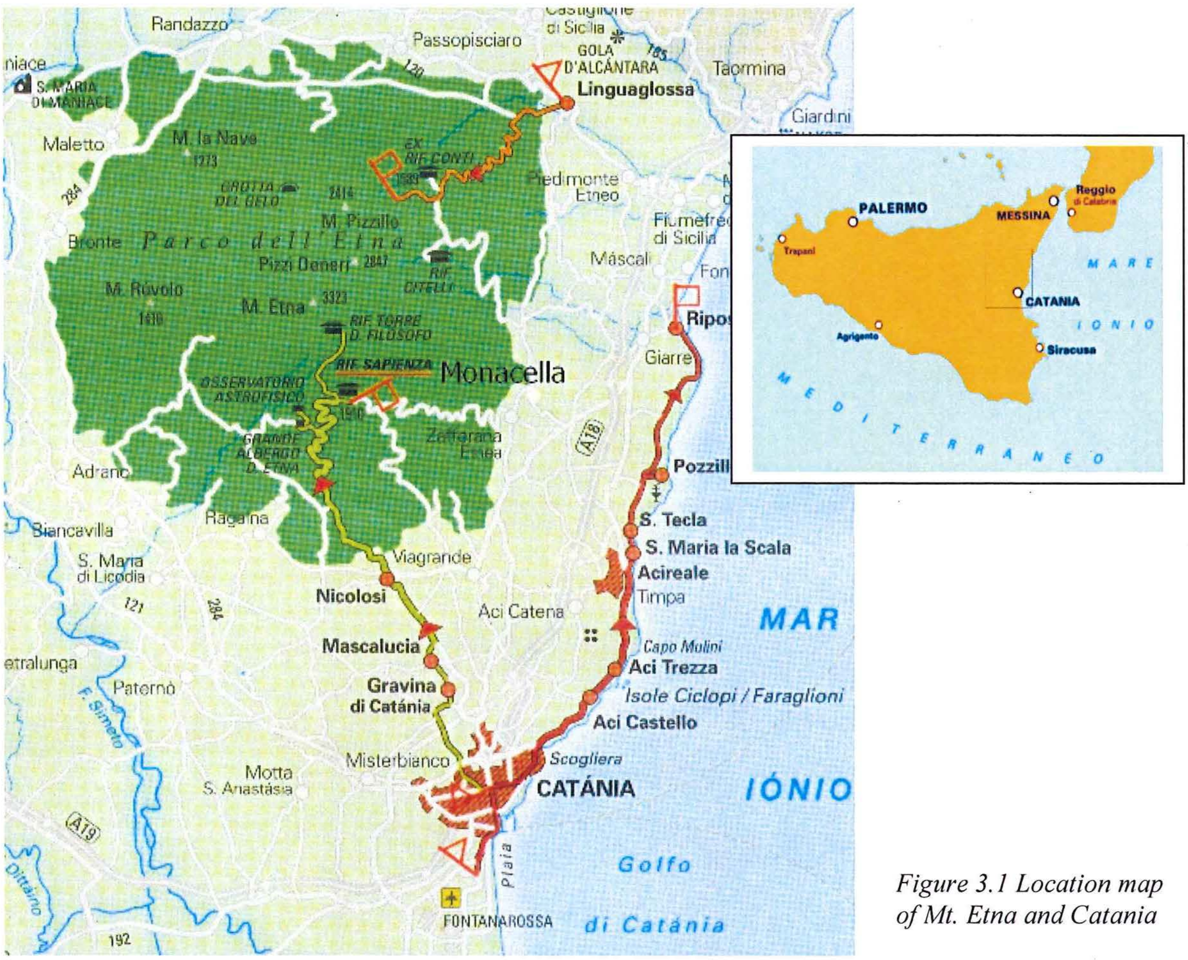


Figure 3.1 Location map of Mt. Etna and Catania

On 27 October 2002, a flank eruption began that would last 3 months, finally ending on 28 January 2003. Eruptive fissures opened on the south and east flanks of the volcano, with both effusive and explosive activity ensuing. Aa lava flows caused damage to property proximal to the volcano, while strombolian and especially hawaiian style activity created large amounts of basaltic ash that would cause damage to more distal areas. Volcanic tremor / earthquakes also resulted in damage to local areas.

During November and early December 2002 fieldwork was undertaken to more accurately ascertain the effects of the volcanic activity, especially of basaltic ash, on the populace and infrastructure of the province of Catania.

Defining these effects provides a useful tool to help quantify the expected effects of the next basaltic eruption in TVZ, especially one from Tarawera. The basaltic ash erupted from Etna is expected to create similar hazards to some of those that will be produced in a near-future eruption of Tarawera. Although Catania is situated at the base of Etna, the size of the volcano (3330 m) is such that the approximate centre of Catania (taken as Giardino Bellini) is 25 km from the vents active on Etna in 2002/2003. Similarly, Rotorua is about 25 km from the 1886 fissure that bisects Tarawera Volcano. Villages/settlements exist closer to the vents/fissure in both cases.

3.2 Hazard types

Hazards associated with the eruption resulted from ashfall, volcanic tremors and lava flows. Lapilli and bomb fallout was restricted to areas in the immediate vicinity of the vent. SO_2 emission, though in large quantities (up to 20,000 tons per day) (Bruno et al., 2002) was sufficiently distant from inhabited areas to cause no health problems to residents, being adequately dissipated by winds. However concern amongst local citizens about the gaseous emissions of Etna led to some people wearing ash masks even when ash was not falling. These would of course have been ineffective had SO_2 or H_2S been a problem, but reassured those unwilling to trust official information.

3.2.1 Lava flows

Several aa lava flows were emitted during the eruption. These caused some damage to forestry plantations and infrastructure on the slopes of the volcano, as they flowed downslope, destroying everything in their path. Damage began with the destruction of a ski school and the hotel "Le Betulle" at Piano Provenzana by lava flows which began on 27 October, the first day of the eruption.

Figure 3.2 Le Betulle Hotel Remains (Photograph by M. Fulle)

These same lava flows also threatened forests near Linguaglossa. However, although destructive, the slow movement of the flows (usually metres rather than kilometres per hour) allowed for mitigation strategies to be employed. An attempt to protect the pine forests was made by Ground crews from the Vigil de Fuoco (the fire department) and Corpo Forestale (the forest corps), as fires created by these flows could easily spread. These crews were supported by helicopters water bombing lava flows from the air (*L'unione Sarda*, 29/10/02). This strategy succeeded in restricting damage to that caused directly by the lava flows, stopping fires spreading far beyond the edges of those flows. Nevertheless over 80 hectares of forest were destroyed (*La Sicilia*, 2/11/02). In addition to the loss of forest, several roads on the slopes of the volcano were destroyed when 3m high aa lava flows passed over them (Figure 3.3).

Figure 3.3 An aa lava flow in the Ragabo Forest destroys the road above Linguaglossa, November 2002

By 2 November the flow approaching Linguaglossa had stopped, 80 m from diversionary earthworks and 5 km from the town. Similar fire-fighting strategies were employed as further flows approached forests on the west side of Etna.

Direct damage from the flows themselves affected also affected other types of infrastructure. Ski lifts on the southern slopes of Etna, near Rifugia Sapienza, were destroyed by lava flows on 24 November. An irrigation reservoir near Casa Santa Barbara was emptied to minimise the risk of a phreatomagmatic explosion when a 4 km long lava flow approached on 17 November, this flow fortunately stopped a few metres before the reservoir.

Creating earthworks to divert lava flows has in the past been employed with some success on Mt. Etna, attempts at this strategy were again made during the 2002 eruption. The flow that approached Rifugia Sapienza on the night of 24 November was successfully diverted by directing it slightly to the east to protect the ski station (figure 3.4)

Figure 3.4 Earthworks around the ski lift station at Rifugia Sapienza, November 2002. Note the lava flow to the left of the picture

However a few weeks later on the night of 16-17 December a second flow that followed a similar path destroyed two buildings beside the ski station. This was in spite of the local fire brigade's efforts to cool the approaching front with water, and the earthworks created with army excavators and bulldozers. An explosion occurred as the lava flow destroyed one of these buildings, caused by a water or oil tank being trapped under the flow. As a result 32 people near to the building were injured, and one car destroyed. The high numbers of people present in this area as the flow approached increased the amount of risk posed by that flow. As well the danger of explosions there was a possibility that the flow could cut off access to Sapienza. Army and Navy excavators were also available to clear the access road to Sapienza should lava flows have cut it off (*La Sicilia*, 12/12/02).

3.2.2 Earthquakes

Volcanic tremors were responsible for damage to several buildings in towns and villages on the slopes of Etna. At the beginning of the eruption on 27 October, continuous shaking in close proximity to the vents (within 1 km) was reported by INGV staff. These were sufficiently violent to make it very difficult to stand, and long enough to induce feelings of nausea (G. Sawyer, *pers. comm.*, 2002). Earthquakes continued throughout the course of the eruption. INGV reports (Azzaro et al., 2002; Azzaro & Scarfi 2002; Mostaccio & Scarfi 2002) indicated that intensities of the earthquakes in urban areas reached up to 6 on the European Macroseismic Scale (EMS-98). (This also equates to 6 on the Modified Mercalli scale, refer appendix 1 & 2). These tremors resulted in damage to buildings in several settlements. Most buildings in the region are constructed of either concrete, though some older buildings are of basalt. Prior to 1981 no building code for earthquake-resistant buildings existed in Italy, and most buildings in the region were built before this (Behncke, 2002). Therefore earthquakes of MM6 caused more damage than they might otherwise have done if more stringent building codes were in place. Most damage was minor, resulting in the cracking of concrete walls and plaster facings. However many of the cracks caused by earlier shaking were further expanded in subsequent events (Mostaccio & Scarfi, 2002). Some older buildings became unstable, reinforcement of exterior walls using wooden struts was then employed to prevent failure. An earthquake on 2 December felt over much of Etna caused damage to several structures in Macchia di Giarre, 4 km WSW of Riposto. Large pieces of masonry fell from the primary school building, which was closed as a result (Azzaro et al., 2002). An intensity of 6 on the EMS-98 scale was assigned by INGV (Azzaro et al., 2002). (MM 6)

The dislodging and or cracking of roof tiles occurred in several buildings. Concrete balconies were also prone to damage, and were observed in some cases to have collapsed. This may have been accentuated by the accumulation of ash on these flat surfaces.

Dry stone retaining walls were a common casualty of the earthquakes, many of these had been constructed without building permits by local residents. The collapse of such features was common during these tremors (figure 3.5). However retaining walls constructed and maintained by local authorities alongside roads in the vicinity of Zafferana Etnea also suffered partial collapse. Road surfaces were affected as well, cracks formed and disaggregation of the seal took place in some areas. Further damage occurred to roads as a result of small landslides near Piano Provenzana.

Figure 3.5 Collapsed retaining wall in Monacella, November 2002

Panic was common among some of the population of these towns. During ash sampling in Monacella on 7 November several people were observed sitting in cars in a local car park, as they were too frightened to remain in their homes. They approached INGV staff, asking when the activity would stop. Earthquakes earlier in the morning had prompted this response. There were also reports of panic among the populace of Zafferana and S. Venerina because of volcanic tremors (Mostaccio & Scarfi, 2002). Many inhabitants from these towns were too scared to remain in their homes. Four hundred households (about 2000 people) were evacuated from Santa Venerina by 29/10, the evacuees housed in "tent cities" prepared by the Civil Protection (*La Sicilia*, 29/10/02). This was mainly a precautionary measure, as many masonry buildings were susceptible to damage even in relatively minor shakes of MM5-6. In the town of Misterbianco, a phone call to a local school to enquire about the effects of a perceived (though actually non-existent) earthquake on the school buildings alarmed the teachers, resulting in the evacuation of 700 children. (*La Sicilia*, 09/11/02, p.26).

The opposite reaction to local tremors was also observed, as some people in real danger from unstable buildings refused to be evacuated – a family of five near Giarre temporarily barricaded themselves into their home to avoid being evacuated by the local authorities after their home was declared to be unfit for use (*La Sicilia*, 5/11/02).

3.2.3 Ashfall hazards

The 2002 flank eruption of Mt Etna resulted in more ash falling on Catania than there had been in living memory. During the first three days of the eruption the Istituto Nazionale di Geofisica e Vulcanologia (INGV) measured a total of 2.5 kg/m^2 of ash falling on Catania, (P. Del Carlo, *pers. comm.*, 2002). Bulk density of the ash samples varied during the eruption, and also with proximity to source. However using a bulk density of 1.6 g cm^{-3} (which a distal sample taken on 7 November yielded), this thickness equates to 1.6 mm. While not a great thickness of ash, it was still sufficient to cause havoc in Catania, as roads became extremely slippery, and numerous traffic accidents ensued. At the same time Nicolosi, approximately 13 km from the active southeast crater received 9.7 kg/m^2 (~6 mm), while the tourist resort of Rifugia Sapienza, under 4 km from source, received 38880g/m^2 (~25 mm) during these three days (Del Carlo, 2002a).

Attributes of the ash

The grainsize of ash falling in any given area varied from day to day, as the activity at the crater waxed and waned, and the plume height varied. A continuum of eruptive styles from hawaiian to strombolian type activity was seen during the eruption. Activity changed from one style to the other on scales of hours to weeks. Often an intermediate style existed, where lava jets pulsated less continuously than hawaiian activity, but more continuously than a strombolian style of eruption. These changes in style affected the ratio of tachylite and sideromelane that dominated the composition of the ash. Tachylite dominated in quieter periods, while an increase in the amount of sideromelane was seen in ash taken from more explosive periods (Del Carlo et al., 2002a). Minor olivine, clinopyroxene and lithics were also present, again to varying degrees as the eruption progressed. (Del Carlo, 2002a, 2002b; Del Carlo et al., 2002a, 2002b).

Grain shape has an effect on the packing of ash deposits, and in turn the bulk density. The blocky morphology of much of this ash contributed to high bulk density values measured in both a proximal (600 m) and distal (12 km) sample. The bulk density measured from the proximal sample was 1.26 g cm^{-3}, whereas the distal sample gave a value of 1.63 g cm^{-3}. Grainsize varied in the proximal sample from 125 μ to 5 mm, with a mode of 750 μ. The sample from 12 km from source (in Monacella) ranged from 750 μ to 0.25 μ, the mode was 63 μ. Figures 3.6 – 3.9 illustrate the morphology and presence of extremely fine grains on samples from Catania (25 km from source), Monacella (12 km from source) and 600 m from the active crater.

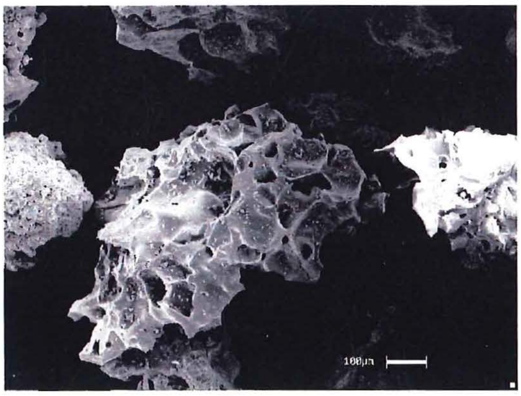


Figure 3.6 SEM of Sideromelane clast from Catania, 11/11/02 (scale bar 100 μm)

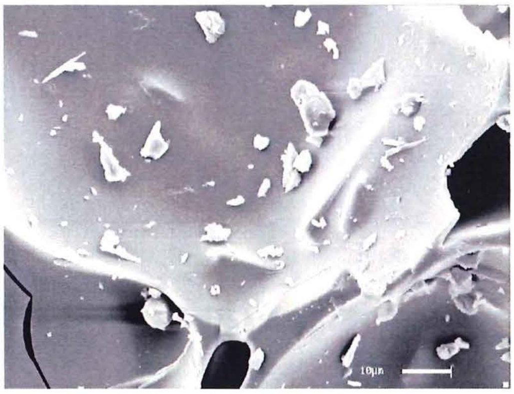


Figure 3.7 SEM close-up of fine grains on sample from figure 3.6 (scale bar 10 μm)

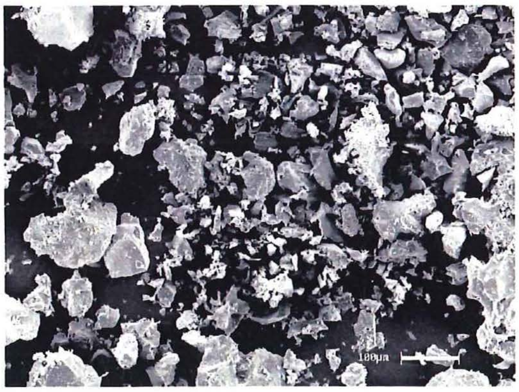


Figure 3.8Sideromelane and tachylite clasts, collected 12 km from source (scale bar 100 μm)

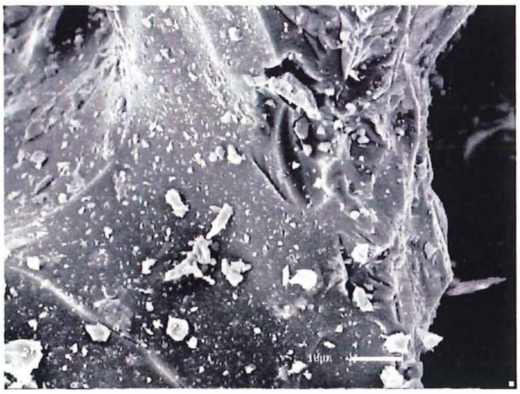


Figure 3.9 Finer particles adhering to a larger clast, proximal sample (scale bar 100 μm)

3.3 Effects of the eruption

3.3.1 Buildings

The weight of ash on roofs did cause some problems, despite accumulations of tephra falling on structures never exceeding 40 kg m^{-2} in any 3-day period, even in proximal areas such as Rifugia Sapienza. (This is not including the Torre del Filosofo observatory, which was buried under a scoria cone built around the active vent). Ashfall was usually not continuous in any one area for more than a few hours during the course of the eruption. This was due to either changes in wind direction, or the waxing and waning of the explosive activity. This usually gave residents time to clean ash from roofs between ashfalls. However in the case of some badly maintained buildings, flat or slightly pitched roofs that were not cleaned accumulated sufficient ash to cause collapse after rainfall saturated them (P. Del Carlo, *pers. comm.*, 2002). Minor structural damage also occurred on houses with pitched roofs that were not cleared of accumulated ash. Although Sapienza was subject to the heavier ashfalls than more distal urban areas, the structures in this resort were designed to cope with snow loading, being situated at 1900m above sea level. In addition, regular cleaning of roofs meant that buildings in this area did not experience damage from ashfall.

Figure 3.10 Rifugia Sapienza November 2002. In the foreground workers clean the restaurant roof while the eruption continues in the background

Roof guttering on buildings in towns on the flanks of Etna was damaged or destroyed in several cases by the accumulation of ash, which blocked downpipes enough that water and ash built up in the spoutings until collapse ensued (P. Del Carlo, *pers. comm.*, 2002). In some cases ash was observed to have accrued at the base of downpipes to such an extent that it blocked the downpipe from the base upwards. However many downpipes on older buildings in Catania end 30 cm or more above the ground, discharging water directly onto footpaths. These were not usually affected by such blockages, as the ash did not accumulate into piles this high before being dispersed.

Removal of ash from rooftops was a labour intensive exercise. This usually involved someone climbing onto the roof and sweeping the ash onto the ground. Ash in spoutings needed to be scooped out by hand. On taller buildings within the city the use of cherry pickers was employed to gain access to rooftops. Again ash was manually scooped up, and then poured over the edge into dump trucks below.

3.3.2 Communications

Little effect on communications was caused by ashfall or the presence of the plume. Mobile phones continued to work as usual, and phone lines remained intact. One possible exception was interference to hand held radios used by INGV staff to contact the base stations in Catania and Nicolosi from near the summit of Etna. Although these worked without problems most of the time, on some days interference occurred. This was despite similar weather conditions existing on days when they did function normally, and attempts at contact being made from the same location. Although not a definite link, it is possible that the plume was responsible for this interference. Mobile phones appeared unaffected, they were used as a backup for communication.

3.3.3 Electricity distribution

No effects on electrical distribution networks were reported to have occurred as a result of the eruption.

3.3.4 Gas supplies

Gas supplies remained unaffected by the eruption. While moderate seismic activity may have been sufficient to burst gas mains, gas supplies in the peripheral towns on Etna are not piped, but stored in tanks on the properties of those who use it.

3.3.5 Water Supplies

Fortunately for the region around Etna, water supplies are derived from subterranean streams/springs which were unaffected by the eruption. However prior to the eruption, the area had been experiencing a drought. This did affect the amount of water available when increased demand occurred as a result of people wanting to wash ash away with garden hoses. A few days into the eruption, on 4 November the drought was broken as rain fell in Catania.

3.3.6 Stormwater/sewerage

The influx of ash into the stormwater system proved to be a problem for drainage in Catania. Siltation effectively blocked some drains completely, and restricted flow in others. Combined with rain, this resulted in localised flooding on several occasions, which affected traffic flow when roads became submerged. Fortunately there was little heavy rainfall in Catania during the course of the eruption. No problems with sewerage were reported, though little data could be gathered on this subject due to some communication (language barrier) problems during fieldwork. INGV staff were unaware of any damage to infrastructure or blockages of actual sewerage pipelines. It was their understanding that sewerage was flushed directly out to sea without any kind of treatment, though this is unverified (P. Del Carlo, *pers. comm.*, 2002). Figures 3.11 – 3.14 illustrate the effects of ash on the streets of Catania.

Figure 3.11, Ash blocking Stormwater drains in Catania, November 2002

Figure 3.12 Ash blocking Stormwater drains in Catania, November 2002

Figure 3.13, Siltation seen in open stormwater drains in Catania, November 2002

Figure 3.14 Flooding as a result of ash blocking drains, Catania, November 2002

3.3.7 Transportation

Aviation

Catania's airport (Fontanarossa) was closed throughout much of the eruption due to the ash plume causing danger to air traffic. Even when the wind was not blowing directly towards the airport (south) the plume could cause problems, interfering with flight paths. The radar used by Fontanarossa airport is not capable of detecting the ash plume (*La Sicilia*, 12/12/02). Therefore on cloudy days it was not always apparent where the plume was. The same applied to night-time. Consequently during the course of the eruption the airport adopted a timetable of opening from 7am until 6pm where possible (*La Sicilia*, 28/12/02). Even then the airport was not always able to open. In addition to the problems caused by the plume, ash had to be cleaned from the runways before any planes took off or landed. Some pilots reportedly refused to fly into Catania, preferring to land in Palermo, or Reggio Calabria (*La Sicilia*, 4/11/02).

Roads

Travelling by road was adversely affected. Traction was affected by both wet and dry ash, even with very small (~1 mm) amounts. Stopping distances increased as vehicles skidded on the slippery surface. Cornering needed to be approached with caution, a driving style similar to that used for driving on ice was necessary to avoid accidents. Frequent minor accidents and falls experienced by riders of motorcycles and mopeds during the first few days of the eruption led to their use being briefly prohibited within the city of Catania. However the extensive use of mopeds as a means of transport in this region necessitated the local authorities lifting the ban, and merely recommending that they were not used. In addition to the hazard caused by the slipperiness of ash on road surfaces, airborne ash was particularly problematic for cyclists/mopeds; it easily got into the eyes, noses and mouths of those riding without masks and goggles or full-face helmets. This was further accentuated as clouds of dry ash were stirred up by passing automobiles. These clouds of ash also reduced visibility on the roads, a problem affecting all road users. Visibility of road markings was reduced to nil with only a small (<1 mm) covering of ash. Ash on roads never exceeded a few millimetres in Catania, except in the occasional drift. Many of the villages on the slopes of Etna have at least a few roads that are steeply inclined. Driving up these steep gradients with even a thin layer of ash on the ground was not always possible in a two-wheel-drive (2wd) car, given the lack of traction. Closer to the vents different problems were experienced with thicker deposits. Between Sapienza and the active crater at 2700 m, a four-wheel-drive (4wd) ski field service track provided access for local authorities to monitor the eruption, and to monitor the numbers of tourists that tried to approach too closely. Although ash deposits on this road were usually several centimetres deep, and at times over 30 cm, 4wd vehicles with differential or hub locks were able to successively drive up the incline. However drifts did have to be smoothed out to ensure their success. An unsuccessful attempt was made to climb even moderate inclines in 2wd, with both thin (>5 mm) and thicker (5 cm) deposits.

Wet ashfall presented different problems. Although water prevented the ash from being stirred up into clouds, during heavy ashfalls the rapid accumulation of ash on windscreens directly inhibited visibility. In lighter ashfalls windscreen wipers were able to effectively clean windscreens (figure 3.15). However during heavier falls it became necessary to frequently stop vehicles every few hundred metres and manually clean windscreens, using bottles of water to clean off the finer particles.

Figure 3.15 Light rain and light ash were easily coped with by vehicle windscreen wipers

The addition of water to ash on the ground does effectively stop it from being remobilised by winds. Rain did not effectively remove ash, as channels formed within the deposit, and the bulk of the mantle of ash remained in situ. The remaining ash compacted and hardened once it dried out. Ash left on the roads could then be driven over, rather than through. However the presence of any wind during ashfall created drifts of ash that in turn created their own hazards. Small drifts acted like "speed humps" in the road, which if driven over at speed could cause damage to vehicles or even accidents to occur. At times larger drifts blocked roads altogether until mechanically removed. While dry ash was removed from roads with the use of road sweepers, the removal of ash that had been dampened or wetted entailed using machinery such as snowploughs and front-end loaders. In urban areas ash was swept more regularly, with both road sweepers and workers with brooms (figures 3.16 & 3.17).

Figure 3.16 Clearing ash off roads in Monacella. Snowploughs proved effective at quickly cleaning deposits of several millimetres off roads.

Figure 3.17 Council workers sweep ash from streets in Catania

As this work was performed in addition to the normal work carried out by the city council workers, the City of Catania was forced to pay overtime rates to its workers to do this. This led to reluctance on the part of the council to clean up the streets until the eruption was over. They did not want to have to do the same job twice. Pressure was put on INGV to give a date for the end of the eruption, which was not possible. However an accumulation of ash over the days then weeks of the eruption would have caused a greater amount of damage, and would have cost even more to clean up. The council was eventually convinced that it was in their best interest to continue to remove ash from streets and public buildings/parks etc (P. Del Carlo, *pers. comm.*, 2002).

3.3.8 Ash Disposal

In rural areas, and especially on Etna itself, disposal of the ash covering roads was usually simple – it was dumped at the side of the road, or over Armco barriers onto recent (i.e. the last century or so) non-vegetated aa lava flow deposits. The basaltic ash is fertile enough that vegetation quickly begins to establish itself in the ash. In fact this property of the ash has led to some of the ash being sold by the local council as fertilizer. Other ash from the cities was used to fill in landfills, the remainder has been dumped into the sea (P. Del Carlo, *pers. comm.*, 2002).

3.3.9 Nuisance value

Many problems associated with the ashfall were not serious enough to be deemed 'hazards', but still were seen as a nuisance. This included things like the curtailment of outdoor dining – restaurants could not serve food outdoors as falling ash would land on meals, making them less than palatable. Even when ash was not falling directly it could still be blown about and into food. This had some economic repercussions on dining establishments. Hanging out washing to dry with ash falling resulted in soiled clothing. Shopkeepers had to continually sweep pavements if a minimum of ash was to be carried into shops on the soles of the shoes of customers. Fortunately the majority of shops in Catania have wooden floors, which made cleaning inside easier.

3.3.10 Agriculture/forestry

Agriculture was adversely affected by the 2002-2003 eruption, at least in the short term. In the long term the basaltic ash that covered crops will act as a fertilizer, enriching the soils. However, industry associated with forestry, horticulture and farming all suffered losses because of these eruption. Although ashfall was never heavy enough to damage the forests, lava flows destroyed 80 hectares of forestry near Linguaglossa between October 29 and November 2 (see section 3.2.1). On 14 and 15 November further damage occurred to plantations near Casa Santa Barbara (on the west side of Etna), as aa flows bisected a forested area. Fortunately these flows largely followed the same path as those from the 2001 eruption of Etna, thus killing only a small number of trees.

Drought conditions throughout October meant little grass had grown around Etna in this month. This lack of fodder for stock, combined with a thin covering of ash on the ground meant that farmers had to bring in feed for sheep and cattle that would otherwise have been able to find adequate grazing on the lower slopes of Etna (*La Sicilia*, 29/10/03).

Fruit and vegetable growers were perhaps the hardest hit economically. Ashfall damaged fruit and drastically reduced its value. Almost one third of Italy's oranges are grown in the region of Catania, along with other citrus fruit, (*La Sicilia*, 09/12/02). 50% of these were lost, ruined by both ash pitting the skin and being absorbed into the fruit (*La Sicilia*, 29/10/02).

Figure 3.18 Citrus fruit damaged by ashfall (photograph from "La Sicilia" 6 November 2002)

Ash on the surface also made the fruit difficult to pick, and it was feared that it could damage machinery used in picking and processing of fruit. Even harder hit were vegetables in general, 80% of crops were lost, (*La Sicilia*, 26/12/02). This damage occurred both in the province of Catania, and that of Siracusa, where crops over 50 km kilometres away from the active vents were similarly damaged. Giuseppe Guastella, President of the Sicilian branch of Italy's federation of farmers "Coldiretti", estimated that agricultural damages to the Catania region cost 80 million euro, Siracusa a further 60 million euro, (Guastella, G., 2002). Furthermore 75% of agricultural jobs were lost during this season, as crops were unable to be harvested (*La Sicilia*, 21/12/02). Locally produced fruit sold in local markets and shops during the course of the eruption was recognisably damaged, or covered in ash. This was not always easy to remove, for example running water over bunches of grapes was not sufficient to remove all of the ash, it was necessary to manually rub the ash off each grape to ensure the fruit was clean. This demonstrates how crops can easily be ruined economically, as the time needed to clean the fruit or vegetable affected is worth more than the produce itself. This damage was not caused by heavy ashfall – most of the affected area was subjected to less than 3 mm of ash by the time this damage was done.

3.3.11 Tourism

Tourism in the region was also adversely affected by the eruption. The closure of the airport was partly to blame for this, which under normal circumstances is Italy's 3rd busiest airport. Italy's tourism association (Assoturismo) reported a downturn in business for hotels etc of 75%. The same association said that business was down by 25-30% in restaurants and pizzerias, 25% in travel agencies and 30 to 35% in ticket offices, (Siciliasearch.com). Only 50% of the usual number of visitors to Catania (for the time of year) were present during the course of the eruption according to an estimate by staff at Catania's visitor information centre.

3.3.12 Effects of the eruption on the populace

Reactions to the eruption ranged from panic to intense curiosity. While some people were too scared to remain in their homes, other people wanted to get as close to the activity as possible to obtain better views of the eruption. Both types of behaviour caused problems for local authorities. The evacuation of over 2000 people from Giarre and S. Venerina was necessary, given earthquake damage to houses, but some residents in other areas also affected by the tremors also wanted to be evacuated – even if this was not necessary. Most people were worried to some degree, especially those with property on the flanks of the volcano. However when asked, many people expressed the view that it was just nature, the volcano was just doing what it had always done. They lived beside the volcano and thus had to live with the consequences (from conversations with local inhabitants).

The desire to witness the spectacle of lava erupting from Etna from close up motivated many other people (both locals and tourists) to attempt to climb to the active vents, or to the front of lava flows. Not only did this put people in immediate physical danger, at times the amount of people approaching flows obstructed emergency services. To attempt to prevent this police put up roadblocks on many roads to restrict access to the mountain. The Department of Civil Protection oversaw the emergency, and directed staff from the fire department, municipal police, national police, provincial police, financial police (who also have an alpine rescue section) and forest corps. They were responsible for manning the roadblocks, preventing people from getting too close to the flows and vents, and rescuing those that were injured or lost. The forest corps and fire fighters were there to stop the spread of fires started by lavas flows burning vegetation. During late November this force comprised 232 staff (*La Sicilia*, 27/11/02). Local alpine guides also patrolled the summit area. Despite these precautions people still attempted to get up close to the volcano. As well as the dangers posed by bomb fallout, volcanic gases and lava flows, the terrain at the summit of the volcano is comprised of jagged (and very sharp) pieces of aa lava, bombs and blocks, scoria and ash. Temperatures can also drop very quickly to sub-zero, as the altitude of the crater was 2700 m. Snow fell in this area on several occasions during the course of the eruption. These factors were often overlooked by eager tourists wanting to get a close view of the eruption, keeping the alpine rescue teams very busy rescuing lost and hypothermic sightseers (Guarda di finanzia officers, *pers. comm.*, 2002). Despite controls on people climbing up to the top, some skirted patrolled areas, on other occasions climbers/walkers were let through from Rifugia Sapienza, the climb of almost 1000m to the active area ensuring that only those fit enough to climb this much would make it to the more dangerous areas. The amount of interest in the eruption meant that it was impossible to keep absolutely everyone away from danger. Reports of impending damage to Sapienza as lava flows approached on 24 November resulted in thousands of spectators trying to drive to Sapienza to witness the sight. On this occasion the roadblocks were emplaced further down the mountain to keep people at bay. Queues of traffic several kilometres long stretched from just outside Nicolosi to the roadblocks. This hampered emergency services in gaining access to Sapienza. On most nights spectators could be encountered at both the sides of the road, and even stopped in the middle of the road. The impact of the sight of a large strombolian explosion, even from four to five kilometres away is not to be underestimated. This created hazards in itself. On return from fieldwork with INGV staff near the active vents, it was not uncommon to see cars that had just stopped, after the drivers rounded blind corners and were confronted with a spectacular volcanic eruption. This of course led to following traffic having to react quickly to avoid crashing into the stationary vehicles.

Health Effects

The short-term effects of the basaltic ash on the regions inhabitants were largely of discomfort, rather than anything serious. Ash getting into peoples eyes was both painful and difficult to remove. It did have the potential to scratch the cornea if eyes were rubbed as opposed to being washed out with water. The wearing of masks to filter out ash particles was a common sight in Catania during the course of the eruption (figure 3.19).

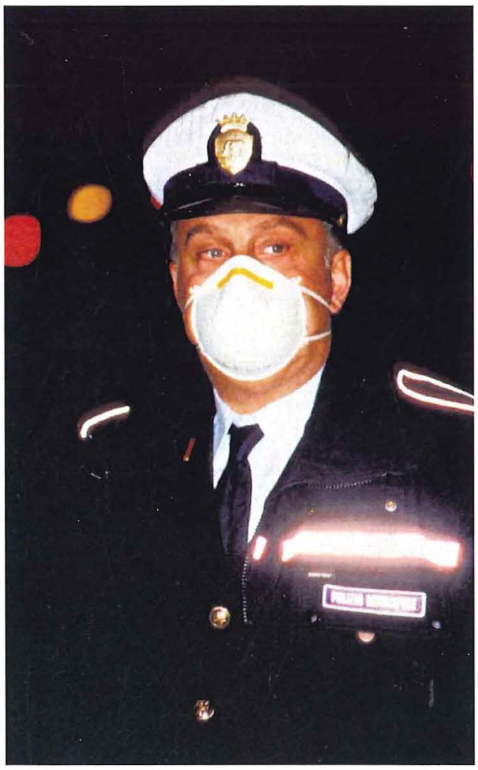


Figure 3.19 A municipal police officer in Catania wearing an ash mask while on traffic duty

Red Cross volunteers were often present on the streets in Catania during ashfall, handing out ash masks to pedestrians. Civic authorities recommended that people should try to keep outdoor physical activity to a minimum during ashfall, and that asthmatics remained indoors during those times (*La Sicilia*, 07/11/02). Staff from the University of Catania's Institute for Respiratory Diseases and the Department of Microbiology are currently conducting investigations into the long-term effects of the ash on human health.

3.3.13 Economic effects of the eruption

The costs of the eruption is not easy to evaluate. A loss of €140 million was described by the national confederation of farmers, or farmers lobby (the Coldiretti) (Guastella, 2002). Judging the loss experienced by the tourism industry is more complicated given the large amount of variables. Over 80 hectares of forestry plantations were lost, several buildings were destroyed by lava flows, roads near Linguaglossa and Sapienza were covered and at least one car was destroyed. Earthquake damage affected many buildings, retaining walls and roads, all off which need to be repaired. As well as damage directly caused by the eruption, several costs need to be taken into account. Loss of employment resulted for fruit pickers and processors as crops were destroyed, the decline in tourism during the eruption had repercussions for local restaurants, retailers, hotels and the hospitality industry in general. Local authorities needed enough manpower to both monitor the eruption and keep the overcurious far enough away to avoid being injured of killed by the eruption. This involved over 200 people for three months (*La Sicilia*, 27/12/02). 2000 evacuees needed to be put into tents and fed. A further undisclosed number of evacuees were housed by relatives or rented alternative accommodation. Clean-up operations took many hours, and were performed by council workers in addition to their normal duties - the workers therefore demanded to be paid at overtime rates. (P. Del Carlo, *pers. comm.*, 2002). As well as roads and public facilities/buildings, the drains had to be cleared of a build up of ash. Traffic accidents occurred as vehicles skidded on slippery surfaces. The cost of closing the airport alone was said by the mayor of Catania, (Umberto Scapagnini) to be around 500,000 euros per day (*La Sicilia*, 29/10/02).

Italy has had to cope with several other natural disasters during this time, notably a landslide in Lombardy, and earthquakes in Molise and Puglia. An aid package of € 700 million, funded by the government was announced in February 2003. This package was to cover all of the emergencies from late 2002 until that time. Catania received a significant portion of this though the exact amount is unknown (*La Sicilia*, 07/02/03). The many costs involved with coping with the eruption make it impossible to place an accurate figure on the cost of the emergency. However it will certainly be in the hundreds of millions of euro dollars.

Chapter 4

Hazards associated with Tarawera Volcano

4.1 Introduction

A future basaltic eruption of Mount Tarawera will potentially cause considerable damage to the Bay of Plenty region. While the exact magnitude and duration of an eruption cannot be accurately predicted, the vulnerability of the region can be assessed. Risk is commonly defined as hazard x vulnerability (Blong, 2000). By determining likely hazards, preparation and thus mitigation strategies can be implemented that will reduce the vulnerability of the region. In this way the risks posed by Tarawera Volcano can be reduced, to minimize both loss of life and damage in the surrounding area. This chapter aims to quantify the likely physical processes of an 1886 type eruption, and thus identify the hazards that may affect the Bay of Plenty region.

4.2 Future basaltic activity at Tarawera Volcano

The magnitude of any future basaltic eruption at Tarawera Volcano is unknown. Predictions of the behaviour of a specific volcano are largely based on past activity, yet there has only been one previous basaltic eruption at Tarawera. While it is probable that a near future eruption from Tarawera will be basaltic (see chapter 1), the only indications of the style of basaltic eruption to occur at Tarawera are given by the 1886 eruption. The violence of this eruption does indicate that Tarawera is a dangerous volcano: any volcano that erupts over 1.3 km^3 of material in around 4 hours is not to be treated lightly.

The effects of a near-future basaltic eruption have been calculated based on an eruption type similar to that of 1886. Using the 1886 eruption as the basis of a hazard evaluation does give an indication of effects likely to occur in the event of explosive basaltic activity. That eruption was the largest basaltic eruption in the 1.6 ma history of TVZ (Wilson et al., 1995). For this reason the magnitude of the 1886 eruption, in terms of volume of ejecta, can be seen as a probable worst-case scenario. Although effusive activity did not occur in 1886 it is a common phenomenon with basaltic volcanism and has accordingly been included as a potential hazard in this assessment.

4.3 Precursory Activity & Monitoring

A future eruption of Tarawera will not occur without warning. There will be precursory signs before the next eruption. The ascention of a body of magma through the earth's crust creates enough movement to be detected by seismometers, and at times tremors strong enough to be felt by people. A swarm of localized earthquakes would be detected weeks to months before volcanic activity manifested itself at the surface. Monitoring at Tarawera is performed by the Institute of Geological and Nuclear Sciences (IGNS). Six seismometers are situated within 30 km of Tarawera Volcano, including one on top of the volcano itself. Although the regional seismic network will indicate any unusual seismic activity, precisely locating magma movement would require further seismometers in the area (Sherburn & Nairn, 2001). Temporary seismometers could be easily installed should localized seismic activity begin in this area. Ground movement is also measured. Ground deformation associated with a magmatic intrusion beneath Tarawera may be manifested at the surface by tilting or bulging of the volcanic edifice. This would in turn result in a change in the shoreline of local lakes. Three water level recorders on the west, north and east shores of Lake Tarawera utilize the lake surface as a level, thus monitoring this type of activity on the mountain. In addition horizontal strain monitoring networks were set up around Lake Rotomahana and the Tarawera Volcano summit in 1983. Though not monitored they can be used in the event of any kind of unusual geological activity at Tarawera (Sherburn & Nairn, 2001). Another effect of magma rising in the crust along the Tarawera Vent Lineation will be changes in the local geothermal activity. A large intrusion of magma will noticeably heat the geothermal system. From 1970 to 1998 the temperature and discharge rates of Frying Pan Lake and Inferno Crater were monitored. The data recorded from these will provide a useful background baseline if monitoring of these thermal areas recommences (Sherburn & Nairn, 2001). This could easily be reinstated if seismometers record unrest at the volcano.

4.4 Expected hazards

Major hazards associated with basaltic volcanism at Tarawera Volcano are as follows:

- Ashfall
- Bomb and lapilli fallout
- Phreatomagmatic eruptions and base surges
- Hydrothermal eruptions
- Lava flows
- Lahars
- Earthquakes & seiching
- Poisonous gases

4.4.1 Ashfall

Ashfall will have the most far-reaching consequences of an eruption. Damage will be widespread, as ash will be distributed over a much greater area than that affected by any of the other hazard types. Most economic damage from an eruption is likely to be caused by ash, though loss of life is unlikely to directly occur as a result of ashfall, as opposed to some of the more proximal hazards. While the same eruption magnitude as the 1886 event is used to evaluate hazards, it is possible that (up to a point) larger or smaller amounts of ash could be deposited in any given area, dependent on weather conditions. The weather conditions experienced in the 1886 eruption were similar to prevailing weather patterns today. Figure 4.1 indicates wind patterns at various heights in the North Island. Winds are less variable at altitude, and it is these winds that have the greatest control on ash distribution. Prevailing winds above 2 km altitude are westerly winds. The summit of Tarawera, and thus the source of the ash, is at 1111 m. Low-level winds (<1000 m) will thus only create local effects on tephra distribution. Figure 5.1 illustrates prevailing wind directions in the North Island.

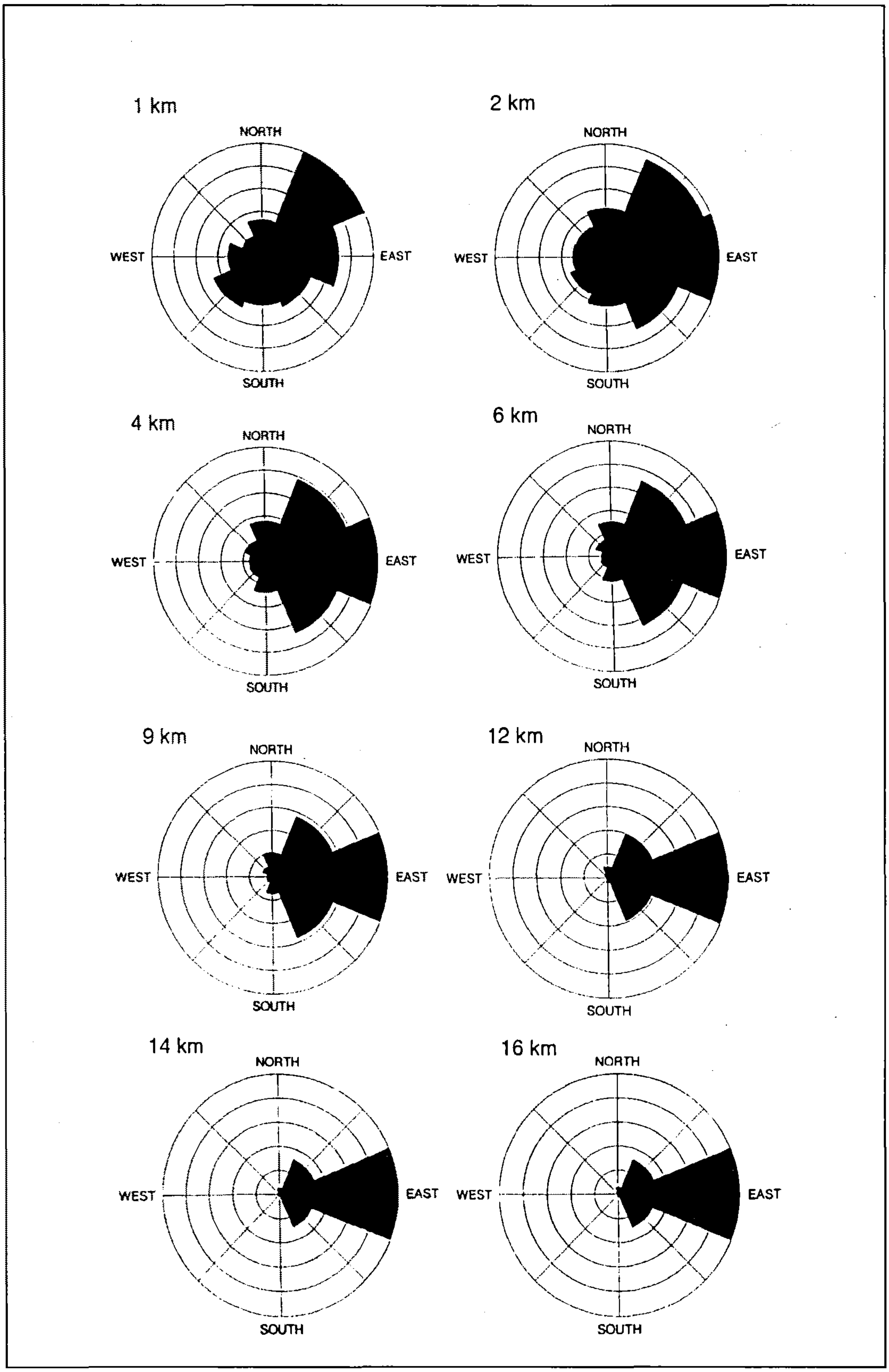


Figure 4.1 The frequency of wind directions at various heights above Auckland airport derived from 1966 to 1979 data (Johnston, 1997)

While existing data on wind direction indicate only a 0.7% chance of winds above 2 km altitude blowing from the east or southeast (which would deposit ash on Rotorua) the possibilities of these effects should be considered. Whakatane and Kawerau are more likely to be affected by heavy ashfall. The southwest winds above 2000 m that would cause the heaviest ashfall to affect these towns occur 20% of the time. Westerly winds are the most common, at 37%. Whakatane and Kawerau would still be affected, but with only light deposits.

Probabilistic models of ash dispersal, such as ASHFALL or HYPACT would indicate a similar dispersal of tephra to that experienced in 1886, or dispersal slightly more east than northeast, assuming prevailing wind conditions. A wind blowing from west to east would result in little or no ash deposition on Rotorua, and possibly none on Tauranga. Instead the slopes of the Ikawhenua ranges would receive most of the ashfall, to the east of Tarawera. Whakatane and Opotiki would receive slightly less ash than during a southwest wind (as experienced in 1886). Parameters needed for ash dispersal models include the magnitude (volume) of the eruption, the height of the eruption column and local wind direction/speed. The magnitude and duration of a future eruption are not only unknown, but more importantly largely unconstrained (though unlikely to exceed the 1886 magnitude). Prevailing winds are known, though regional variations (which affect results) are not taken into account in these programs (Turner & Hurst, 2003). This large amount of variables involved in predicting future basaltic activity at Tarawera would thus make results unreliable. It is therefore preferable to determine likely effects based on the 1886 scenario, but to include the possibility of thicker deposits of ash in areas feasibly affected if winds were different. In this way any differing wind conditions may be taken into account, and the worst-case scenario effects established for each of the main centres in the Bay of Plenty Region. The ashfall hazard map in figure 4.2 therefore does not represent ashfall expected from a single event, but gives an indication of the maximum expected thickness in any one area, contingent simply upon distance from source. Wind direction is not taken into account.

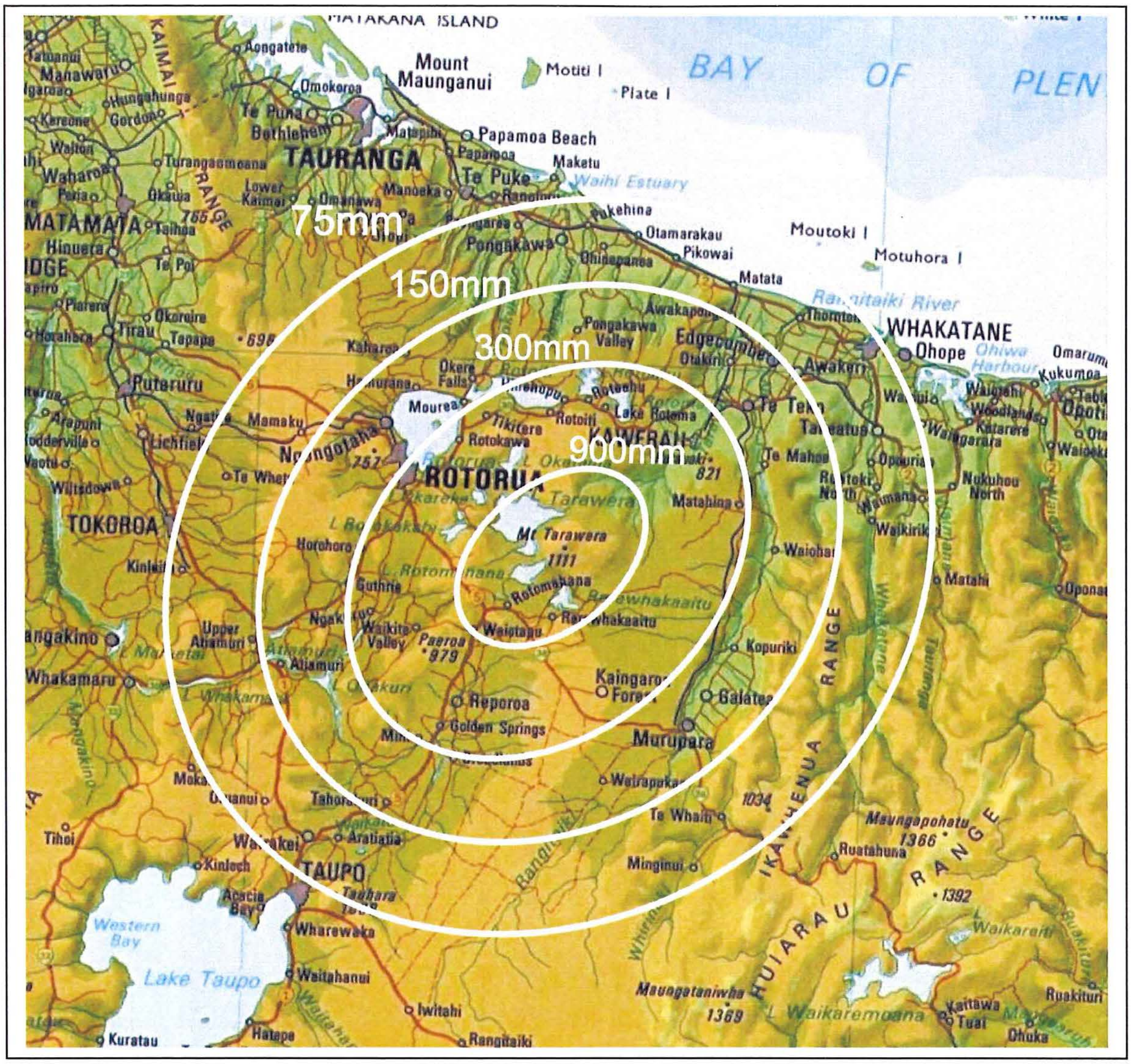


Figure 4.2 Maximum thicknesses of ash possible at any location under1886 conditions

Properties of basaltic ash affecting hazard evaluation

In terms of hazard evaluation, one of the most important properties of volcanic ash is its density. This will determine the load that it imposes on structures subject to ashfall. The density is governed by its mineralogy, vesicularity, grain shape, compaction and water content. The density of basaltic ash from a future eruption of Tarawera is an unknown factor, but it can be estimated. To do this, Tarawera 1886 and fresh Etna 2002 ash samples were collected during fieldwork. A coarse proximal sample from Etna was collected on 11 November 2002 from within 600 m of the active crater. A more distal fine sample was collected on 7 November in Monacella, 12 km from source (see chapter 3.) Constraints on the volume of samples taken were made by the necessity of carrying them from Italy to New Zealand. Samples were weighed by volume (1 litre) to establish bulk density. The bulk density of the Etna samples was measured at 1260 kg m^{-3} for the proximal sample to 1630 kg m^{-3} for the distal sample. To compare with Tarawera, two samples collected from Ngamotu Road (10 km from the Tarawera fissure) gave bulk density values of 1051 and 1074 kg m^{-3}. These agree with bulk density values given by Walker et al., (1984) as varying from 900 kg m^{-3} near the vent to 1100 kg m^{-3} distally. Although bulk density is lower than the Etnean samples, the density of the actual clasts from Tarawera was higher than average (Walker et al., 1984). Table 4.1 lists the average density of Tarawera's 1886 scoria clasts by grainsize.

Table 4.1 Average densities of 1886 scoria clasts (after Walker et al., 1984)

Grain size (mm)	Average Density (g cm^{-3})
16 - 32	1.40
8 - 16	1.40
4 - 8	1.54
2 - 4	1.68
1 - 2	1.86
0.5 - 1	2.00

Given the high density of Tarawera scoria clasts, the bulk densities for Etna seem particularly high. However the magnitude of the Tarawera 1886 eruption was far greater than the Etna 2002 eruption. Samples taken at similar distances from source are therefore much coarser from Tarawera than Etna, and consequently have a lower bulk density. Walker et al., (1984) do not indicate where the distal samples measured for bulk density were sampled. Measured bulk densities may therefore have included greater values if samples were taken further from source. This may not have been possible given the weathering of fine ash over the ~100 years since the eruption.

The weathering of the ash prior to sampling may also explain large differences between the densities of Tarawera and Etna. Samples of Tarawera tephra taken from Ngamotu Road in 2002 during fieldwork for this thesis show a depletion of fine material. It is possible that samples collected in the 1980's by Walker et al. were also depleted of fine ash, leaving coarser vesicular material to be weighed, thus giving lower values for bulk density. SEM pictures of these samples do show more fines present in Etna samples. Furthermore vesicular clasts from Tarawera 1886 contain vesicle fillings, a textural feature of partly altered volcanic ash (Heiken & Wohletz). This also indicates changes to the ash subsequent to deposition (figure 4.3)

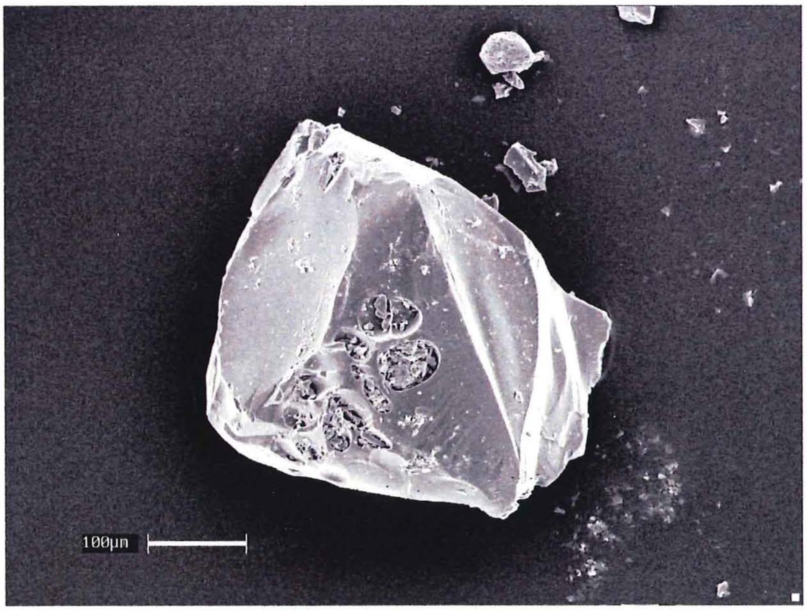


Figure 4.3 Tarawera ash sample showing sideromelane with vesicle fillings

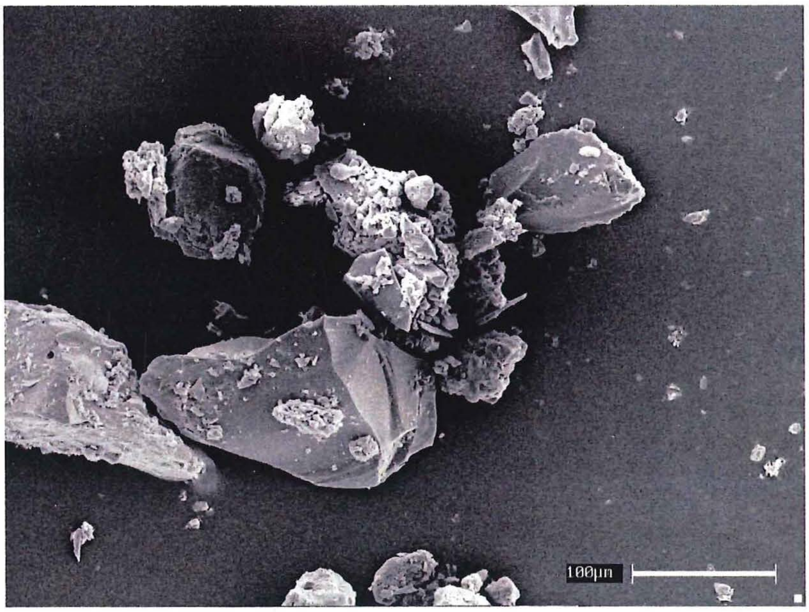


Figure 4.4 Tachylite and Sideromelane clasts from Tarawera. Less fine samples are present here than in typical slides from Etna

A large amount of pre-existing rhyolitic material was also mixed in with the 1886 ash, as the explosive activity of the 1886 eruption fragmented large amounts of Kaharoa rhyolite from Tarawera volcano in creating the present day craters. Walker et al., (1984) give a figure of 10% by volume for non-basaltic material. This will also have an effect on the density of the ash, especially as some of that material is pumiceous (figure 4.5)

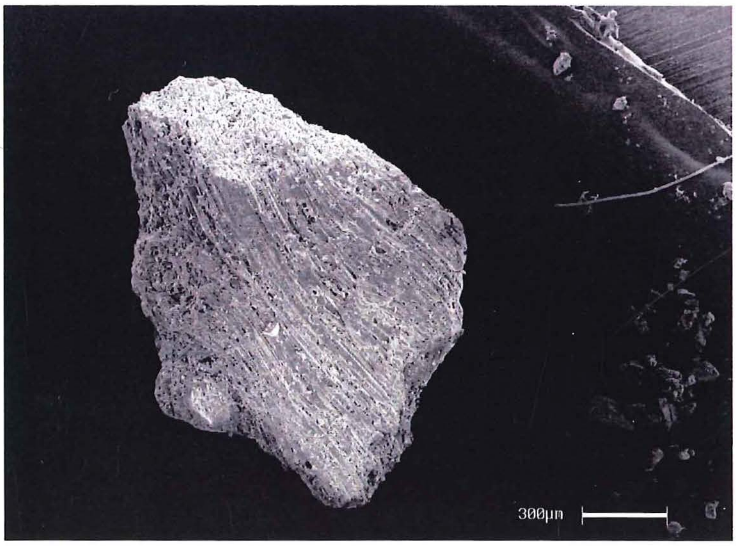


Figure 4.5 Pumice clast from Tarawera ash

For these reasons the freshly sampled Etna 2002 ash is thought to be more indicative of possible future ash densities from Tarawera. Although a component of rhyolitic lithics will possibly be included in future activity, the plane of weakness created by the 1886 basalt dikes will most likely be exploited by ascending magma. Thus the surface would be reached without significant amounts of overlying rhyolite being fragmented.

In order to determine likely tephra loading from future basaltic activity, values from the distal material collected are more applicable – few buildings are found close to Tarawera Volcano. Parts of Spencer Road are within a 10 km radius, as are a few houses to the southeast of Tarawera. However the Etnean "distal" sample measured for density was collected only 12 km from source. Even the densities of Tarawera samples from Ngamotu Road, 10 km from the 1886 fissure, were closer to the higher distal values given by Walker et al. (1984) than proximal ones. Tephra loading for structures at this range may therefore also be calculated using the distal values calculated. The 1630 kg m^{-3} bulk density value determined from Etna is rounded down to 1600 kg m^{-3} for use in these calculations. This takes into account the possibility that the values measured from the 1886 may not only be erroneous, but may be exceeded in future activity. This value (1600 kg m^{-3}) is not expected to be significantly exceeded by future Tarawera ashfalls since these densities are high for typical bulk densities of tephra.

An estimation of wet ash densities is also required to calculate the effects of tephra loading on roofs, in order to determine when roofs are likely to fail in the event of rain. The proximal and distal Mt. Etna ash samples were left soaking overnight to achieve maximum saturation, and weighed after excess water was decanted off. Wet density of the ash was found to be 1710 kg m^{-3} in the coarse proximal sample (750μ modal grainsize) and 2086 kg m^{-3} in the fine more distal sample from Monacella. The samples respectively absorbed approximately 45% and 46% water by volume. The Tarawera samples from Ngamotu Road took less water to fully saturate. Wet density of these two samples was found to be 1455 kg m^{-3} and 1480 kg m^{-3}. This ash thus absorbed around 41% (by volume) of water before becoming fully saturated. A sample of Rotomahana mud was also weighed, as this may add weight to tephra loads. A wet density value of 1880 kg m^{-3} was obtained. This is not expected to differ significantly in a future eruption of Rotomahana. A rounded value of 2000 kg m^{-3} is used in calculations of wet density for future Tarawera tephra. This is again slightly less than the maximum Etnean wet ash density value.

4.4.2 Bomb and Lapilli Fallout

In addition to the problems caused by the inundation of ash, the potential for immediate and potentially severe damage from the impact of bombs and lapilli exists. An 1886 type eruption will disperse scoria over a wide area. Walker et al., (1984) mapped scoria fragment distribution from 1886. Taking the 3 largest scoria fragments found from each of 120 sites, an isopleth map was created. Results indicated the maximum distance traveled by scoria clasts (by diameter) are given in table 4.2

Table 4.2 The maximum distance travelled by different sized scoria clasts in 1886

128 mm	07 km
64 mm	12 km
32 mm	20 km
16 mm	30 km
08 mm	38 km

Often the direction that clasts traveled furthest in was southeast, which was at 90^{O} to the wind conditions at the time. This is indicative of partial control by ballistic trajectories. These trajectories would in turn be dictated by vent geometry. Wind would still have influenced the paths of scoria clasts as the distances traveled by scoria exceed that possible for ballistic trajectories alone. Furthermore no clasts were found to have traveled any appreciable distance directly into the wind. However the initial trajectories of larger clasts will influence their final distribution, thus even areas that are not directly downwind of the plume may be subject to lapilli and scoria airfall.

Prediction of ballistic trajectories of large clasts in future activity is not possible given the unknown vent geometry. As wind direction during future activity is also unknown, these clasts may feasibly affect any area within the distances given above. During basaltic activity Rotorua will thus be in range of lapilli up to 16 mm diameter. Kawerau will be subject to clasts over 32 mm, but under 64 mm. Other settlements included within the 32 mm isopleth are Lake Okareka, Waiotapu, Rotomahana and several small settlements on the south side of Lakes Rotoma and Rotoiti. Spencer Road, less than 12 km from the summit of Tarawera may be subject to clasts of 64 mm and over.

Projectiles pose hazards in two different ways – damage can be caused by impact, or clasts may still be hot enough to cause fires upon landing.

Impact energy

The impact energy of ballistic clasts is a function of the density, mass and diameter of those clasts, and the velocity at which they are traveling ($E_K = \frac{1}{2} mv^2$; Blong, 1984, p.25). Terminal velocity is reached in only a few tens of metres, therefore the impact energy can be easily established by calculating the size, mass and density of the clasts. Blong (1984) refers to the density of clasts ranging from about 0.15 to 3.6 g cm^{-3}, however this includes highly vesicular pumice, with a much lower density than basaltic material, and dense lithics from the vent walls. Clast density from Tarawera 1886 scoria is given in table 4.1.

Ballistic ejecta impact hazards will affect buildings, infrastructure, vehicles, trees, crops, people, and livestock. Details of effects are given in chapter 5.

Ignition from projectiles

Ignition of buildings or foliage by incandescent bombs has been documented in several cases, including the 1975 eruption of Ruapehu, where bombs struck Glacier Hut, charring wood and burning through the floor (Blong, 1981). Bombs between 0.1 and 2 metres diameter from the 1973 Eldjfell eruption at Heimaey also started fires after penetrating house roofs and windows (Booth, 1979). The 1886 Tarawera eruption may have caused fires as a result of incandescent bombs landing on buildings – the Haszard household burnt down during the eruption, and “red hot stone” was seen landing on the house (Keam, 1988, p.134). However it is unclear whether this was the cause of the fire. Projectiles larger than 5 mm may remain hotter than the surrounding gas dispersion (Sparks and Wilson, 1976). The larger the projectile, the hotter the interior will remain. Incandescent projectiles landing on Te Wairoa were no larger than about 40 mm, many were smaller than this. It is possible that even projectiles as small as 20-30 mm will remain hot enough to start fires if they land in dry vegetation. For example in 1914 at Japan’s Sakurajima Volcano, bombs ignited forest undergrowth 4.7 km from source (Omori, 1916, cited in Blong, 1984). This type of hazard may occur again at Tarawera, especially as the volcano is largely surrounded by forest. An eruption occurring in the summer will naturally prove much more hazardous in terms of fire danger. Fires resulting from ignition by incandescent projectiles may cause widespread damage to forests. These may be hard to control, both from the danger of projectile impacts to firefighters, and because fires may be started in several areas at once.

4.4.3 Phreatomagmatic eruptions/Pyroclastic surges

Eruptive style

Explosive activity between the north end of Rotomahana and Waimangu during the 1886 eruption of Tarawera was influenced primarily by the interaction of magma and groundwater, and to a lesser extent the lakes of Rotomakariri and Rotomahana. Pyroclastic base surges were created as Taalian style eruptions ejected water, lake sediments and basalt fragments up to 11 km into the atmosphere (Nairn, 1979). However the explosion craters that were generated by this eruption subsequently filled with water, creating the present day Lake Rotomahana, a much larger lake than the combined Lakes Rotomahana and Rotomakariri of pre 1886.

Lake Rotomahana currently has a surface area of 7.95 km^2, and a long axis of 6.2 km. Its mean depth is 60 m, though at its deepest point (the Great Crater Basin) it is 150 m (Donald et al., 1991). These dimensions give it a volume of 0.48 km^3, considerably larger than in 1886. The changes to the environment in this area will influence future magmatic activity should it occur here. To illustrate: Rotomahana occupies 6.2 km of the 17 km long eruptive fissure of 1886, i.e. 35% of its length. Walker et al., (1984) estimated 0.7 km^3 of material (DRE) was erupted in the 1886 eruption. This was calculated assuming a total ejecta volume of 2 km^3 from dense basalt at 2800 kg m^{-3}. 90% of this was juvenile basaltic material, the rest rhyolitic material and ash & mud from Lake Rotomahana, therefore 0.63 km^3 of basaltic magma was erupted. Using the Pullar and Birrell (1973) figure of 1.3 km^{-3} would give a dense rock equivalent of 0.46 km^3. If 90% was juvenile basalt, 0.41 km^3 of basalt was erupted. Assuming that the basalt was essentially evenly distributed along the length of the fissure, 35% of it would have intruded under the present day Lake Rotomahana. Depending on which volume is used, this equals between 0.22 km^3 and 0.14 km^3 of magma. The larger volume is just under half the volume of Lake Rotomahana. The small amount of basaltic material found as a component in the Rotomahana mud may of course indicate a smaller magmatic source, and/or that quenching took place and little magma was explosively. The style of future activity in this area will in part depend on the amount of magma that is intruded into the geothermal field and Lake Rotomahana. Nairn (1979) calculated a solid volume eruption rate (for the 130 minute duration of the Rotomahana to Waimangu part of the eruption) of 6 x 10^4 m^3s^{-1}, with large explosions at between $10^5 - 10^6$ m^3s^{-1}. Future eruptive style at this location in an 1886 type eruption would depend on several factors. Sub-aqueous explosive activity is possible in freshwater, to a maximum pressure of 216 bars – a depth of 2160 m (Cas and Wright 1987). This is far deeper than the 60 - 150m depth of Rotomahana, which does make explosive activity a possibility. It is also feasible that quenching of lavas may occur – assuming that magma reached the lake water without first triggering phreatomagmatic explosions in the geothermal system beneath the lake floor. The depth of water plays an important role in determining eruptive style, as does the temperature, viscosity and volatile content of the magma, and how much magma is interacting with the water at any one time (i.e. the magma-water ratio). This ratio will depend on the surface area of magma exposed to the water, in turn determined by the extrusion rate and area of exposure. In terms of converting thermal to mechanical energy the most effective ratio of water to magma mass is ~ 0.3. With a ratio less than 0.1 dry strombolian activity will ensue, over 0.3 and eruptive styles range from surtseyan to subaqueous quenching of lavas (Sheridan & Wohletz, 1981).

Dikes from the 1886 eruption were from 1 to 5 metres wide (Cole & Hunt 1968, Nairn & Cole, 1981). Although the intrusion underneath Rotomahana would exist under the entire length of the lake, the actual exposure of magma to water would (as in 1886) occur in discrete areas, making an estimation of the surface area of magma contacting water difficult to ascertain. Furthermore the vesicularity of the magma will influence the surface area exposed to water. The margin of error in any attempt to determine actual surface area in this way will be fairly large, given the amount of variables in such a construct – especially when predicting future activity. Observations of basalt-water interactions at Surtsey, Heimaey and Hawaii do however indicate probable results. With a gradual effusion of non-vesiculated lavas, the volume of lake water at Rotomahana would result in quenching of lavas and the creation of (unconfined) steam. This would act as an insulating layer against the violent interaction of water and magma (Kokelaar & Durant, 1983). Much less explosive activity would therefore ensue. However magma may become explosive through the release of volatiles without any interaction with water – something that is still possible under low hydrostatic pressure. While the maximum volatile fragmentation depth (or VFD) may differ according to magma type, the 150m maximum depth of Rotomahana is shallow enough for this to be considered a possibility (Kokelaar, 1986). These magmatic explosions would then generate further explosions from instantaneous quenching and the accompanying creation of steam (Kokelaar & Durant, 1983). The likelihood of (initially) purely magmatic volatile exsolution taking place beneath the lake is perhaps not as probable as an interaction of magma and groundwater. The extensive hydrothermal system in this area is likely to be intersected (or even exploited as a pathway) by ascending magma, providing many opportunities for phreatomagmatic explosive activity beneath the lake floor. As the magma rises through the wet sediments, some of these deposits will be incorporated into the rising melt (Kokelaar, 1983; Kokelaar & Durant, 1983). Trapped water will then be flashed to steam, becoming violently explosive as the steam expands. The subsequent phreatomagmatic explosions may then remove enough overburden to expose more magma to lake water, creating further explosions. The hydrostatic pressure of the lake waters will affect activity on the surface of the lake: the explosions beneath or at the lake floor will be partly suppressed by this pressure, the chilling effect of the water and the inertia of the containing water (Kokelaar & Durant, 1983). Ballistic dispersal of material is thus restricted. For these reasons, explosivity will increase in shallower areas, and as the depth of water decreases. The high rate of extrusion may lead to the build-up of either volcaniclastic sediments, pillow lavas or both. This would increase the level of the vent, again resulting in an increase in the violence of explosions. The 1963 eruption of Surtsey demonstrated this type of activity (Kokelaar & Durant, 1983). Should the duration of the eruption be long enough, the vent may eventually become subaerial, whereupon phreatomagmatic activity would become purely magmatic, and thus less explosive - assuming the vent was enclosed sufficiently to prevent the access of lake waters (Kokelaar, 1983). However it is important to realize that despite possible quenching effects of the lake waters, the probability of extremely violent phreatomagmatic activity is still very high at Lake Rotomahana. The risk of phreatomagmatic activity occurring in the geothermal valley from Rotomahana to Waimangu is also very high. The hydrothermal systems here are expected to act as the Rotomahana ones did in 1886 – by explosively interacting with the basaltic magma. Initial explosions created by expanding steam as magma interacted with groundwater would remove overburden, resulting in depressurization of the hydrothermal system, hence causing further hydrothermal explosive activity (Nairn, 1979).

Pyroclastic Surges

The results of violent phreatomagmatic explosions from Rotomahana to Waimangu will be the creation of large unstable eruption columns, which may collapse to form pyroclastic base surges. The generation of the columns from Rotomahana will be similar to wet Surtseyan type activity. Consequently the reduction of energy caused by the heat exchange between the magma and the lake water will reduce the heat that drives the convecting plumes. Condensation of steam may also take place, increasing the density of the column, which in turn leads to column collapse and the generation of secondary pyroclastic base surges (Nairn, 1979). Larger explosions of the 1886 eruption are thought to have been powerful enough to "generate primary base surge by direct sub-horizontal outward flow from the vents" (Nairn, 1979). Through the expansion of Lake Rotomahana and the extension of the geothermal field to Waimangu, the amount of water available to interact with magma has increased. This renders base surges even more of a probability in a near future eruption of Tarawera.

Pyroclastic flows and surges typically travel at speeds of tens of metres per second, although primary blasts have been observed to advance at up to 300 m s^{-1} (Wilson & Houghton, 2000). For example the 1980 Mount St. Helens lateral blast traveled at up to 150 m s^{-1} (540 km/h) (Nakada, 2000). Temperatures within flows may reach hundreds of degrees Celsius. During the 1992 eruption of Unzen in Japan, temperatures of up to 660^{O}C were determined (Nakada, 2000). Surges from Rotomahana may be cool (possibly less than 100^{O}C), as they will be formed from wetter surtseyan type activity. However phreatomagmatic surges may also be hot (Cas & Wright, 1987). The actual temperature of surges will be influenced by the magma-water ratio; less water equals drier hotter flows, more water will produce cooler wetter flows (Sheridan & Wohletz, 1981).

Pyroclastic surges are less dense than pyroclastic flows, typically containing 0.1 – 1 % by volume of solids – even close to the ground where density is greater (Wilson & Houghton, 2000). For this reason the effect of topography on surges is minor; they may travel over ridges, into valleys and over higher ground again, as opposed to denser flows, which follow lower ground. While containing less solid particles and more gases than flows, the speeds and potential high temperatures of surges still render them extremely destructive.

The pyroclastic base surges from the 1886 eruption traveled at least 6 km to the west of Lake Rotomahana, traveling over hills 350m higher than the vents. Proximal deposits near the great crater exceed 20m thickness (Nairn, 1979). The villages of Te Ariki and Moura stood in the path of these surges, and were consequently completely destroyed. The only trace of their previous existence was an upright from a whare, discovered in 1887 in a stream at the bottom of one of the Rotomahana craters (Keam, 1988).

The greater extent of the lake and hydrothermal system have now created further areas at which hydrovolcanic activity may create either primary or secondary base surges. Moreover it is possible that future surges may travel in any direction from source. This mainly depends on vent orientation in the case of primary surges, and wind direction in the case of secondary surges or plumes (Wilson & Houghton, 2000). As a result, hazard zones for pyroclastic surges need to be considerably in excess of the extent of base surges deposits from 1886.

Surges from sub-plinian to plinian eruptions do not usually travel more than about 10 km (Valentine & Fisher, 2000). This is of course still substantially further than the 6 km extent of 1886 flows. In some cases they may exceed this, for example the 18 May 1980 surge at Mt. St. Helens traveled ~35 km, the 1883 Krakatau basal surges reached about 80 km (Valentine & Fisher, 2000). Krakatau was a much larger eruption though, and the Mt. St. Helens surge was initiated by a lateral blast & sector collapse – the topography at Rotomahana (i.e. a lake rather than a mountain) would preclude this type of mechanism from occurring. Therefore base surges would not be expected to exceed a 10 km radius from the vents. Even then 10 km is a worst-case scenario, surges are not expected to travel far beyond the 6 km experienced in 1886. The 10 km figure quoted is for sub-plinian to plinian type eruptions. 6 km is more indicative of the magnitude of Vulcanian type activity. The increase in lake size and extent of the geothermal system will not increase the size of surges, only the size of the source area for those surges. However it is possible slightly larger explosions could occur, 10 km is thus used as a safer estimate of the maximum extent of pyroclastic base surges (figure 4.6).

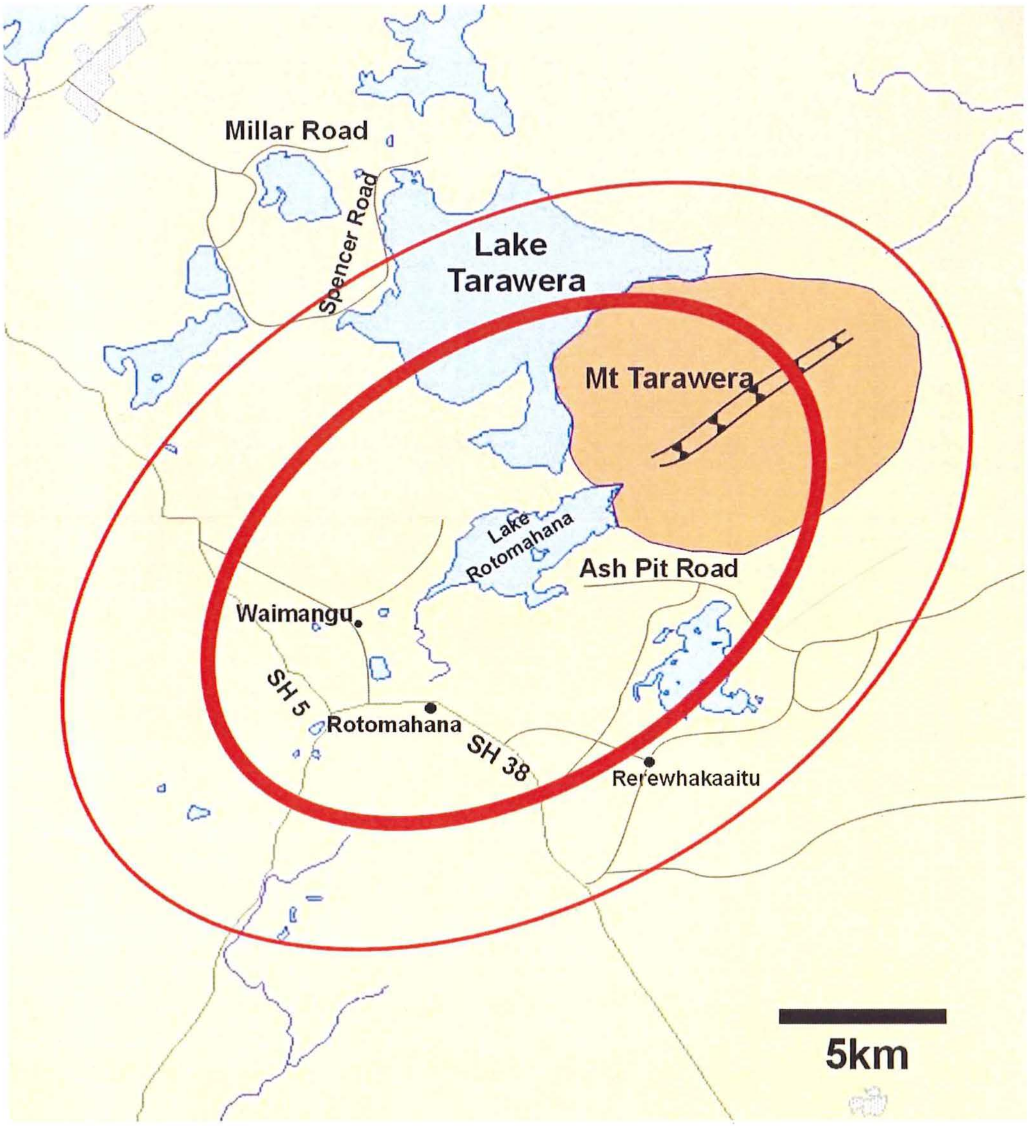


Figure 4.6 Pyroclastic surge hazard map. The thick (inner) red ellipse indicates the likely extent of pyroclastic surges in any direction, the thin (outer) ellipse is a maximum possible from this type of eruption.

Airfall

Not only will ejecta from Rotomahana be deposited by pyroclastic surges, significant amounts will be carried further by the eruption plume. Mud will be distributed over a wide area adding to the load already imposed on structures by ashfall. It will not be remobilized into the air as easily as dry ash given its high water content. While the permeability of the ash is expected to prevent it from being easily remobilized from slopes (White et al., 1997), the high water content of the mud deposit will make it much more likely to form lahars. Mud from the 1886 eruption was deposited as far as Whakatane and Maketu to the northeast and north respectively, and Galatea to the southeast. Thick deposits of wet mud created extreme difficulties for traveling along Tarawera Road between Te Wairoa and Rotorua after the 1886 eruption, as mudflows from hillsides above the road inundated it in the days and weeks after 10 June.

Flooding

An additional problem which may occur as a result of the intrusion of magma into the waters of Lake Rotomahana is the raising of lake waters by displacement. Although much of the water would be heated to boiling point and thus driven off as steam, the maximum quantity of magma calculated as being available to enter the lake is 0.22 km^3 – almost half of the volume of the lake. While most outflow from the lake is subterranean, an artificial outlet exists on the northeast side of the lake, draining water into Lake Tarawera. This outlet may become blocked by sediments ejected in the early explosions of a Rotomahana eruption, or even from ash and scoria from a magmatic eruption of Tarawera itself. Subsequently the lake level may be raised by several metres. This would inundate farmland along the eastern margin of the lake, flood the first few hundred metres of the Waimangu geothermal valley, and possibly cause significant spillover into Lake Tarawera at Rapatu Bay. Even without blockages the lake may rise quickly enough that outflow into Lake Tarawera would not keep up with the input of magma.

4.4.4 Hydrothermal eruptions

A high level intrusion of magma into Okataina Volcanic centre will heat groundwater and existing geothermal systems. This will cause changes to hydrothermal activity in the region. The geothermal field at Waimangu will be affected to a larger degree than other fields, due to its location along the Tarawera Vent Lineation. Much of central Rotorua may also be subject to more intense hydrothermal activity than normal, as the city is largely built upon an active geothermal field. This area experienced several changes to the geothermal activity during the 1886 eruption, and is likely to again. New geysers are expected to appear and existing ones to change their behavior. Localized hazards from explosive hydrothermal eruptions can be expected, and muddy or rocky ejecta may damage property or injure people close by. Active geothermal areas such as Kuirau Park, Whakawerawera and Arikikapakapa golf course would therefore need to be closed in the event of a scientific alert level 3 or over. The possibility of large hydrothermal eruptions in the Rotomahana-Waimangu area after the main event cannot be discounted for months or even years after the eruption.

4.4.5 Lava flows

Although the 1886 eruption was entirely explosive it is possible that a future basaltic eruption of Tarawera Volcano could produce effusive lava flows. These could originate anywhere along Tarawera Volcano north of Rotomahana.

Below Tarawera's bushline (700-800 m on the northwest side, 900-1050 m on the southeast) the flanks of Tarawera Mountain are covered in native bush and scrub. The only infrastructure is a small prefabricated building used to collect fees by local tour operators. Native bush gives way to exotic plantations on the flatter slopes of the volcano through till Edgecumbe. Lava flows originating on Tarawera Volcano will travel downslope through these forests, slowing and ponding in flat areas at the base of the volcano. On the western margin of the volcano, lava flows reaching Lake Tarawera would be quenched upon contacting the water. Explosions similar to those seen at on Hawaii's coast where pahoehoe flows from Kilauea reach the sea are only possible when waves enter lava tubes or reach lava in a confined space, thus creating steam explosions (Peterson & Tilling, 2000). This is thus unlikely in the lake, unless a storm or seiching create big enough waves to splash onto a fast moving flow – and unimportant as it is highly unlikely anyone would be close enough during a large eruption to be put at risk. While hummocky type terrain will result in lava ponding, and thus stop flows from traveling very far, a lower slope angle will not stop flows. They may not travel as fast as lava flows on steeper slopes, but they may travel further. This is because flows on flatter slopes are thicker than those on steeper inclines, and thus take longer to cool and solidify (Kilburn, 2000). Effusive activity at the north end of Tarawera Volcano could result in flows bisecting the Waiaute Stream, as it curves around the north end of the volcano. Consequently this waterway could be dammed as lava flows transect it. Localized flooding may then result behind the dams. Quenching of lavas and small steam explosions may also arise at the lava-water interface.

The actual distance traveled will be greatly affected by the duration of the eruption; without lava continuing to be produced at the vent and extending the flow front onwards by gravitational force, forward movement will slow, then stop. Given land use in the proximal area, direct damage from flows will be restricted to the destruction of forests, whether native bush or commercial plantations. However the impacts of the flows on the forests will not be restricted to those areas buried by lava; fires caused by lava flows may spread far beyond the limits of the flows themselves. A risk exemplified by Mt Etna is that effusive lava flows may occur at the same time explosive activity takes place from another source. Should the eruption be explosive at the same time that effusive lava flows are starting forest fires, access to the fires may not be possible due to the danger of ballistic ejecta (scoria & bombs) striking firefighters. Ash plumes and ballistic ejecta may also hamper helicopters or aircraft firefighting with monsoon buckets. This increases the risk of fires becoming much larger before reaching areas that firefighters could safely access. Thus more damage would be done, and the larger fires would be less controllable. Another danger for firefighters near lava flows in vegetated areas is methane type explosions from burning vegetation. Partly burned plants buried by an advancing lava flow release organic gases (such as methane), which may mix with atmospheric oxygen to create a volatile mixture. This can be ignited by the heat of the lava, resulting in explosions of molten spatter. Alternatively the gases may travel tens of metres beyond the flow margins, exploding beyond them and turning dirt, rocks and shrubs/trees into projectiles (Peterson & Tilling, 2000).

4.4.6 Lahars

Lahars are a possible consequence of the large volume of ash that will be distributed over the Bay of Plenty region, however they are not a high risk. They were noticeably absent during and immediately after the 1886 eruption, due in part to the gentle relief of the area, and to the high permeability of the tephra deposit (White et al., 1997). The 1904 lahar that swept down the Tarawera River, occurred as a result of the collapse of a tephra dam blocking up the Lake Tarawera outlet, rather than downslope remobilization of tephra by rainfall. The Tarawera River is the most likely path for lahars to follow, as its catchment area is on Tarawera Volcano and from Lake Tarawera. Thus the thickest deposits of the eruption would be likely to be remobilized along this path. The danger of debris blocking up the outlet to the lake will still exist, and this will need to be carefully monitored after an eruption, to ensure dams do not form. Even a blockage lasting days or weeks will have the potential to rupture suddenly, releasing lahars to travel downstream and inundate areas along the course of the river.

Although the tephra deposits are not likely to cause lahars, the mud likely to be erupted from phreatomagmatic activity at Rotomahana will be susceptible to remobilization. Numerous small lahars may eventuate in steep areas, possibly inundating roads and damaging property.

4.4.7 Earthquakes

Due to their shallow origins, earthquakes induced by the volcanic activity will be more localized in terms of their effects than tectonically induced earthquakes. While not expected to be devastating, effects approaching MM 6 may be expected in close proximity to the volcano, e.g. the Spencer Road settlement could experience shaking of MM 5 - 6. This value is calculated from descriptions and reported damages of the effects of earthquakes in 1886, and from the effects of earthquakes associated with the 2002 eruption of Mt. Etna. Although structural damage occurred to buildings around Etna, many of those buildings are old masonry structures built prior to the establishment of effective building codes in Italy. No major structural damage is expected to structures around Tarawera from earthquakes, due to higher building standards in New Zealand. Even wooden buildings as close as Te Wairoa stood up to the earthquakes of 10 June 1886 without suffering damage from this particular hazard. The earthquakes will be strong enough to be felt by everybody, and they may contribute to panic amongst inhabitants of the area, especially if accompanied by the sight of a large eruption. Earthquakes that continue after the eruption may cause more problems than those prior to or accompanying the eruption, as loose sediments (ash, mud and lapilli) will be remobilized, creating landslides that will damage property downslope. The road from Lake Tarawera to Rotorua will be particularly at risk from this type of sediment movement, due to both its proximity to the Volcano and the steepness of parts of the terrain that it travels through. This was a major problem subsequent to the 1886 eruption (see chapter 2).

Seiching of lakes will also occur during volcanic earthquakes - particularly Lakes Tarawera and Rotomahana given their proximity and depth (average depths 50 m and 60 m respectively, Donald et al., 1991)). Waves created may damage boats moored on, or close to shore, and the boat sheds near the north end of Spencer Road on Lake Tarawera.

4.4.8 Poisonous gases

Gases such as H_2S and SO_2 may be hazardous to the health of people or livestock downwind from eruptive activity. This will only occur in close proximity to the active vents, as these gases are rapidly dispersed by winds. However earthquakes in thermally active areas may create gas bursts, as pockets of accumulated gases such as H_2S and CO_2 are released due to earth movement. Precedents of this have occurred. For example in 1999 in the Alban Hills Volcanic District in Italy, seismic activity released a large flux of CO_2, resulting in the deaths of 30 cows by asphyxiation (Beaubien et al, 2003). In built-up areas this type of activity may result in asphyxiation of people as lethal amounts of CO_2 or H_2S trapped in confined spaces are released. Parts of Rotorua are subject to this kind of hazard, including a significant portion of the CBD. Investigations of gaseous hazards are still in progress in this area, but lethal amounts of H_2S and CO_2 are presently degassing from several fumaroles in Rotorua (Dr M. Durand, *pers comm.*, 2003).

Chapter 5

The effects of a basaltic eruption on lifelines, infrastructure, agriculture and forestry in the Bay of Plenty region

5.1 Introduction

The hazards detailed in chapter four will affect the Bay of Plenty region in different ways depending on proximity to the volcano and on the amount of ash in any one area. This chapter seeks to assess how those hazards may affect the region. Identifying the vulnerability of lifelines for the major urban areas may help to reduce the risk posed by basaltic volcanism at Tarawera Volcano. The effects of future ashfall on given areas are broadly described in terms of light versus heavy deposits. In this way, the vulnerability of the Bay of Plenty region to the effects of any future basaltic activity at Tarawera Volcano can be assessed, without being constrained by one specific scenario. Furthermore the possible distal effects of basaltic volcanism elsewhere in TVZ on the Bay of Plenty region may be inferred from this same study.

5.2 Lifelines & Infrastructure

5.2.1. Transportation

Roads

In the event of heavy ashfall causing major damage to lifelines, infrastructure and inhabited areas, access to devastated areas will depend largely on roads. Should evacuations of urban areas be necessary after an eruption, overland transport will be the only viable option for towns of any reasonable size that are not on the coast. Aeroplanes will have nowhere to land, helicopters will only be available for a small number of evacuations, e.g. small isolated communities or evacuees needing urgent medical attention. Rotorua and Kawerau will depend on roads both to evacuate residents, and to provide access to other utilities before repairs can be effected.

Roads will be covered in varying amounts of ash depending on their proximity to the volcano, slope, aspect (hills facing towards or away from the volcano), wind and local topography. Immediate effects of ash on roads will range from poor visibility and traction through to being them being rendered completely impassable. Table 5.1 describes the effects of different amounts of basaltic ash on road use, based on observations from Etna.

Table 5.1 The effects of basaltic ash on road use

Thickness of ash	Effects
0-2 mm	Road markings obscured, traction reduced (wet and dry ash), visibility reduced as dry ash is remobilized by traffic and wind. Steep hills difficult for 2wd vehicles to climb
2-20 mm	Moderate hills become difficult for 2wd vehicles to climb, steep hills impossible. Drifts cause larger humps in road. Once dampened and compacted it becomes firmer, easier to drive on.
20-100 mm	Slight inclines may be impassable to 2wd vehicles, 4wd vehicles need differential or hub locks to climb moderate hills. Larger drifts (eg 300 mm) may hinder or stop 2wd vehicles on flat roads
100-300 mm	Uneven surfaces in the ash stop any 2wd vehicles, compacted damp ash on flat surfaces is still able to be driven on. 4wd utility type vehicles (not cars) may be able to slowly progress on the flat. Drifts may need to be cleared. Moderate inclines difficult, but may be possible for experienced 4wd drivers. Steep inclines generally impassable. Ruts easily formed on hills.
>300 mm	Compacted ash may be driven on by 4wd vehicles, softer patches may easily bog vehicles. Gradual inclines possible on compacted ash, but after a few vehicles ruts in the ash will form, hindering uphill progress for further vehicles

Essentially basaltic ash acts like sand when driven upon. Damp and compacted, it is dense enough to support vehicles without them sinking in very much and becoming bogged. Whether vehicles “bog” in the ash is not only dependent on how well packed and compacted thick ash deposits are, but on tyre width, vehicle weight and driving style (presence of wheelspin etc.) Exacerbating matters, less dense patches exist where drier windblown ash may form drifts, creating obstacles and affording less traction. Attempting to drive uphill on thick deposits of dry ash can be compared to driving up sand dunes. However, experience at Mt. Etna shows that driving up moderate inclines on thick deposits of ash and lapilli is possible in four-wheel-drive (4wd) vehicles. INGV 4wd vehicles (amongst others) regularly climbed from Rifugia Sapienza to the active craters approximately 700 m higher, using a 4wd track that was regularly covered in ashfall. Thick ash deposits tens of centimetres deep that were not part of tracks were also driven upon without difficulty.

Figure 5.1 INGV staff take IR spectrometer readings on Etna 2002. Note the ash-covered track used to access site

While roads with thick deposits of ash are likely to be closed, travel of this type may be essential in some circumstances. For example overland travel on thick ash may be necessary in evacuations, for search and rescue type activities, or for access to essential utilities that need to be repaired. 4wd vehicles travelling in thick ash deposits would be well advised to travel in convoy, and to carry towropes and spades. Extra fuel may need to be carried as local petrol stations may be cut off from supply tankers, and vehicles driving over thick ash deposits will require more fuel than normal road travel. Many residents evacuated during or prior to the eruption will try to return to their homes to assess damage after the end or perceived end of the eruption. However less important roads will probably not be cleared of ash for weeks after an eruption, some residents will want to return much earlier than this to recover what they can. Local authorities will have to decide which areas are safe to let people back into, even if only temporarily to retrieve property. This will apply to areas close to the volcano that could be covered in a thick mantle of tephra, such as Spencer Road or Kawerau. In some areas access may not be possible at all. For example the Spencer Road community is likely to be essentially inaccessible by land, unless winds were strongly blowing from the northwest during an eruption. The tephra in this area is likely to be supplemented by mud deposits from explosions at Lake Rotomahana, creating thick muddy deposits on the road between Tikitapu (Blue Lake) and Te Wairoa, cutting off the Spencer Road community entirely. An evacuation of this area will be essential before the start of an eruption, as this road is the only route for residents to escape on.

While thick deposits of ash are likely to result in closed roads, thin ash deposits (<5 mm) will probably still be driven on after or during an eruption – the size of the area possibly affected (e.g. most of the Bay of Plenty) will necessitate this as alternatives will not exist in many areas until clean-ups are completed. The reduced visibility on roads created by ash remobilized by wind and passing traffic will result in much slower travelling times. Visibility will be similar to that experienced on dry dusty unsealed roads, but on roads which usually have a much higher traffic volume than the average gravel road. Major roads possibly affected would be most of State Highway (SH) 2, SH 38 and SH 5 anywhere north of Taupo. Oncoming traffic will face extreme visibility problems as vehicles pass each other. The burial of road markings will also affect traffic, as even 1 mm of ash may render them invisible. Urban areas will be more affected by this given the amount of markings present. Speed limitations will need to be temporarily lowered. The frequency of road accidents increased around Etna during ashfall from the 2002 eruptions; it is expected that this will also happen in New Zealand under these difficult driving conditions. The conditions will also slow emergency services in reaching accident sites.

Rainfall on ash deposits can be beneficial, but also brings its own set of problems. A light rainfall may sufficiently dampen ash enough to prevent it from being remobilized by winds, but too much rainfall will result in fine ash being turned to mud. As well as this mud creating further traction problems for vehicle traffic, the ash will be carried in suspension by the water, subsequently blocking up drains and culverts. In rural areas this may result in streams diverting over roads rather than through the culverts designed for them, not only causing flooding but possible scouring causing erosion of road surfaces. In urban areas stormwater systems will be inundated with large amounts of ash. Even moderate rainfall may then cause surface flooding. These problems were experienced in Catania during Etna's 2002 eruption, localised surface flooding quickly occurred during brief showers. The main consequence of this was to hamper traffic movement. Fortunately no heavy sustained rains occurred while ash blocked up drains, serious flooding was thus avoided. During the May 1980 eruption of Mt. St. Helens it was quickly realized that ash was blocking drains, but residents were using water to clean ash off properties. As a result fines of US $200 were introduced for anyone caught dumping tephra in stormwater drains, along with the threat of having their name printed on the front page of the paper (Blong, 1984). Ash was swept 0.5m from the gutter to help reduce the amount flushed into the stormwater system. Stormwater drains were protected by sandbags when 1.5 mm of ash was sluiced off roads by fire hoses in Portland, Oregon, for the annual Rose festival (Blong, 1984). While apparently effective, protecting drains with sandbags will also prevent water from entering the stormwater system through those drains.

Not only will roads be affected by ashfall, in some areas they are at risk of destruction and or burial from base surges. Even assuming a maximum radius of only 6 km, pyroclastic surges from the Rotomahana area may reach several roads. State Highway 5 lies within 3 km of Waimangu, the expected limit of where phreatomagmatic explosions may initiate base surges. This main Rotorua–Taupo route would therefore be cut off during an eruption, and would have to be closed even if an eruption was feared to be imminent – i.e. at scientific alert level 2 this would be advisable, at 3 essential (refer appendix 3 for scientific alert level descriptions). Travelling at 50 m s^{-1} (a conservative estimate) it would only take 1 minute for a pyroclastic surge to reach SH 5, at approximately 1 km northwest of the SH 38 intersection. A powerful laterally directed blast may achieve this in 30 seconds. Should pyroclastic surges actually travel in this direction, the road would be destroyed, probably for several kilometres of its length. Anyone caught on the road (or in the path of a surge) may be killed by one or more of various means; most causes of death in pyroclastic flows are attributable to asphyxiation and thermal distress (Nakada, 2000). Asphyxiation occurs as overwhelming amounts of ash are breathed into the lungs (Baxter, 2000). Impact from objects picked up by the blast is a possible cause of death, as is burial by volcanic material. SH 38 (near the intersection with SH 5) also falls easily within range of pyroclastic surges, and several kilometres could be destroyed (see figure 4.6).

Cleaning of roads

Methods for clearing ash off roads depend on the thickness of the ash and whether it is an urban or rural location. Areas covered in very thick deposits (over 30 cm) would need to be cleared with heavy machinery – bulldozers and front-end loaders. This may not be economically viable (at least initially), dependent on the area being cleared. More populated areas will be prioritised. In areas with average thicknesses of this amount, larger drifts would make clean-up operations very difficult. Thicknesses of ash over ~3 mm will require graders or trucks equipped with snowploughs to clear roads. In rural areas ash may usually be swept into piles at the side of the road. The amount of time needed to clear up ashfalls will depend on the availability of equipment and staff to perform those tasks. Graders and snowploughs will be necessary to quickly clean thick deposits of ash from roads, front-end loaders and trucks to remove that ash, and road sweepers to finish the last millimetres. In most rural areas blading ash to the side of the road may suffice. This will not be possible in all areas, depending on local topography and land-use. In addition to plant material available locally, in the event of an eruption, machinery could be brought in from other centres. Most plant required to clean up will come from Works Infrastructure or Fulton Hogan, though other roading sub-contractors will have additional machinery that may be used. Equipment available from Bay of Plenty and nearby works depots is displayed in Table 5.2.

Table 5.2 Works Infrastructure plant in the greater Bay of Plenty area, as of June 2003. (Unpublished data from Works Infrastructure Ltd, Bay of Plenty East Coast).

	Rotorua	Whakatane	Taupo	Tauranga	Opotiki
Graders	5	3	4	4	1
Super Trucks	2	1	1	1	1
Tractor Brooms	3	-	-	3	1
Loaders	5	2	3	5	2
Tippers	10	4	4	8	4
Snow Ploughs	-	-	2	-	-
Water Carts	4	2	3	2	1
Excavators	1	2	3	3	2

(note, "super trucks" are general purpose trucks fitted with rotary brooms on the front, used for sweeping debris off roads)

Figure 5.2 Works Infrastructure equipment available to clear ash from roads. Clockwise from top left: loader, tipper, excavator, grader

Additional equipment may be sourced from several other depots within 3 hours driving time if required. The Rotorua Works Infrastructure depot is located on SH 5, just south of the SH 30 intersection. This may be subject to a ~30 cm deposit of ash during an eruption, in the (unlikely) event of east or southeast winds. Should machinery still be present (if precursory activity had not prompted a temporary relocation of equipment) vehicles would be partially buried in tephra. Staff may experience difficulties in getting to the plant. Assuming they were travelling from Rotorua (if no evacuation had taken place), their vehicles would likely also be buried. 4wd vehicles may be able to travel on the flat roads of Rotorua, but would first need to be extracted from the ash. Even then the presence of the small hill near Whakawerawera, between Rotorua and the Works Infrastructure depot would probably stop the vehicle travelling any further. The remaining kilometre would have to be travelled on foot. Staff would then have to rely on the excavator and loaders digging themselves out of the ash, before clearing pathways for evacuations and access for outside help could begin. For this reason it is recommended that in the event of precursory activity suggesting activity at Tarawera Volcano, road-clearing equipment should temporarily be relocated to depots further away from Tarawera.

Gravel Roads are more problematic than sealed roads when it comes to cleaning off ash. Sweeping off the last layer of ash is not possible without also sweeping off gravel. The removal of 40 mm of ash from gravel roads in Adams County after the Mt. St. Helens eruption also resulted in the loss of 40 mm of gravel from the road surface (Blong, 1984). Similar experiences are expected here, which will necessitate the acquisition of large amounts of replacement road metal. Many gravel roads in the area are privately owned forestry roads, repairing them will be up to the companies themselves.

An instantaneous clean up of ash is not possible; in some areas ash will not be cleaned for days, weeks or possibly even months. Problems associated with remobilization of ash may then be experienced, as ash is blown back onto the roads both from the sides of roads and the area affected as a whole. Eventually this will be stabilized as plants begin to take hold in the ash, but this may take months to years. Ash in cultivated fields may be ploughed in if deposits are less than 200 mm (Johnston, 1997). This will stabilize the ash, as well as fertilizing soils. In this way the amount of ash blown onto roads around pastoral land will be reduced. Finer ash will be more easily remobilized than coarser ash – so even thin distal deposits will create visibility problems as ash is entrained in the air by even light winds. The redistribution of wind-blown ash into areas already cleaned will also hamper recovery efforts. Dampening ash will help to stabilise finer material and prevent it from being moved by wind. Other stabilization methods involve the introduction of dust palliatives. Various substances were applied to roads to try to stabilize ash in the USA following the Mt. St. Helens eruption of 1980. These are described in table 5.3.

Table 5.3 Dust palliatives employed after the 1980 Mt. St. Helens Eruptions. (Data from Blong, 1984)

Area used	Palliative applied	Successful?	Other
Spokane County	32% Calcium chloride solution	Y	-
Grant County	Rock salt	Y	Hygroscopic, needs high humidity to work
Adams & Whitman Counties	Liquid sulphonate	N	Expensive, water-soluble, needs 2 applications to work
Oregon	Coherex (petroleum resin emulsion)	Y	Non-toxic

An investigation into the effect of dust palliatives on unsealed roads in New Zealand was conducted by Bartley Consultants for Transit New Zealand in 1995. This study investigated the use of two calcium lignosulphates, “Weslig 120” and “Borresperse CA”, as well as a slow-break bituminous emulsion, and waste oil. The results showed that the first three test materials were effective for at least 5 weeks, but that waste oil was much more effective, and much cheaper. However waste oil is not as environmentally friendly as the other products, and may cause later problems when ash was to be disposed of on a more permanent basis. The lignosulphates are a by-product of the pulp and paper industry, and may thus be sourced locally, which would lower costs. In the event of an eruption the acquisition of such palliatives may not occur in time, unless they were in current use to suppress dust on gravel roads. Several other products are also useable as dust palliatives though. These include water, lime, cement, grass, vegetable oil, dilute molasses, and animal fats. Salt water is better than fresh due to the hygroscopic qualities of salt. However the use of hygroscopic or deliquescent chemicals is not so effective in dry areas, when humidity is less than 30%. For a fuller description of dust palliatives see Bartley Consultants, 1995.

Using dust palliatives is of course a temporary method to control the remobilization of fine ash; tephra will still need to be cleaned off road surfaces and removed from stockpiles at the sides of roads. In urban areas it is necessary to remove the ash completely. This then requires somewhere to put the ash. Examples from the Etna 2002 eruption of where to dump large quantities of ash include burial in landfills, the sale of ash as fertilizer and dumping at sea. While the potential environmental impacts of dumping basaltic ash at sea are not fully understood, the large quantities of ash already present in the ocean following an eruption (both from airfall and ash carried out to sea by rivers) may already have done what damage there was to be done. This is an area that requires further research. Furthermore the 2001 Auckland lifelines report indicated that expected costs of marine disposal of volcanic ash are an order of magnitude greater than those estimated for disposal on land (Johnston & Becker, 2001). Certainly the quantities of ash that will be present in urban areas will quickly fill up landfills, options for disposal of ash may run out, necessitating marine disposal.

The cost of cleaning roads

After the sweeping of ash into piles at the sides of roads to quickly clear them, the ash will have to be removed, especially in urban areas. The cost of disposal of ash depends on how much ash there is, how far it needs to be transported and the actual cost of disposal. The May 2001 Auckland engineering lifelines group assessed this problem, and calculated costs of 30c per cubic metre per kilometre for transportation, and $3 per cubic metre for disposal (Johnston & Becker, 2001). These costs do not include the costs of the initial clearing of roads, or time to load ash onto trucks. Disposal costs will vary depending on where this occurs. Even cleaning up about 1 mm of ash from the 17 June 1996 Ruapehu ashfall in Rotorua cost over $53,000. This included cleaning the CBD, kerbs and channels in urban areas, plus cesspits in all areas (Johnston & Becker, 2001). The cost of cleaning roads that have been covered by surge deposits may equate to the costs of creating new roads, depending on the amount of welding of material (this is less likely for base surges than pyroclastic flow deposits) and the thickness of deposits. This will need to be evaluated if or when it occurs.

Effects of basaltic ash on vehicles

Provided sensible precautions are taken, the effects of basaltic volcanic ash on vehicles can be minimal. INGV vehicles, used almost daily on Mt Etna, show no ill effects from frequent trips up to the crater areas. Some of the vehicles in daily use (in 2002) by INGV Catania were over 10 years old and still running well. These included Fiat Panda 4wd cars and a 1980's Range Rover. Staff indicated that the ash had little effect on the cars (M. Coltelli, *pers. comm.*, 2002). While evidence from other eruptions does indicate that volcanic ash can cause engine air filters to easily block up (e.g. Mt. St. Helens May 1980; Blong 1984), this is easily remedied with regular cleaning and replacing of the filters. Closing windows and stopping fans or air-conditioning from taking in air from outside will also reduce the amount of ash entering vehicles. Moving parts may be subject to abrasion by ash, and fine ash does penetrate many areas in vehicles (Foxworthy & Hill, 1982). However damage is only expected if vehicles are already in a state of disrepair that may allow ash to more easily enter moving parts. For example split CV (constant velocity) boots would allow ash to abrade CV joints in a matter of a few hours driving time. Well-maintained vehicles are expected to cope with careful driving in light ashfall or on ash-covered roads. Driving during heavy ashfall is not advisable, due to extreme visibility problems. Abrasion of windscreens by wipers clearing ash off windscreens was reported during the 1945 Ruapehu eruption (Johnston, 1997). This was not encountered in Italy during Etna's 2002 eruption, either during personal experience of driving during light ashfall, or from discussions with residents and tourists about the effects of driving in heavier ashfalls. Differing ash composition, grainsize/shape and vesicularity will influence the hardness and abrasiveness of the ash, which may account for this. Damage to automobile paintwork from tephra has also been reported to have occurred in several eruptions, e.g. Ruapehu 1945 (Johnston, 1997), St. Helens 1980 (Blong, 1984). Again this was not experienced during fieldwork at Mt. Etna; paintwork on INGV vehicles showed no signs of blistering or abrasion (aside from "abrasion" caused by ordinary Italian traffic). The chemistry and gas volatile content, and thus acidity of tephra from individual eruptions will differ, consequently affecting the potential for corrosion and blistering of paintwork. The acidity of tephra from a future eruption of Tarawera is however an unknown quantity, so the possibility remains that paintwork on vehicles and infrastructure (e.g. painted iron roofs) may be affected in this way.

Aviation

Air transport will be severely affected by a basaltic eruption. While the plume is present it will be extremely dangerous for air traffic. Aircraft encountering ash plumes are susceptible to abrasion of all forward facing surfaces, frosting of windshields, damage to onboard avionics and damage or destruction of engines. Potential damage to aircraft by ash has been well documented in the past and does not need to be reiterated here (e.g. Blong, 1984; Casadevall et al., 1996; Miller & Casadevall, 2000). Radar present in the area is not able to detect the presence of ash clouds (Johnston et al., 2000a) therefore flying at night or in cloud during an eruption can result in aircraft flying into ash clouds without warning. However an eruption of the short duration experienced in 1886 will not affect aircraft flying over the region for long. The plume will be quickly dispersed by winds after the cessation of the eruption. In the region inundated by tephra, the presence of ash on the ground at airports will stop aircraft from taking off or landing. During the 1996 Ruapehu eruption, Rotorua received a ~1 mm ashfall on the airport, requiring a substantial clean-up before it was re-opened (Johnston et al., 2000a). With the possibility of 30 cm of ash landing on Rotorua during an eruption of Tarawera, the subsequent re-opening of Rotorua airport may take a long time.

5.2.2 Buildings

Proximal Impacts

Ballistic impact damage

Damage from projectile impacts will depend on the material being struck, the mass of the projectile and the angle of incidence, given terminal velocities. Figure 5.3 illustrates the effects of bomb density, mass and diameter on impact energy. Galvanized iron is a common roofing material around Tarawera. Studies by Blong (1981; 1984) have shown that this can be damaged (especially around fastenings), by bombs larger than 250-500g, or around 40 – 55 mm diameter. Penetration of steel cladding will occur with projectiles over 2.5 g cm^{-3} that are over 2000 g (>90 mm) (figure 5.4). Repeated impacts on the same site will also weaken cladding materials. Bombs 50-60 mm in diameter (again depending on mass) will penetrate or at least severely damage roofing tiles, whether they are clay, fibre–cement, asphaltic, slate or wooden. Roofing may be more at risk during the early part of an eruption, prior to the buildup of tephra as this may actually create a cushioning effect against impacts. Glass may be penetrated by projectiles of even 10 g, almost all glass (excepting laminated glass) will be penetrated by projectiles over 25 g (Blong, 1981).

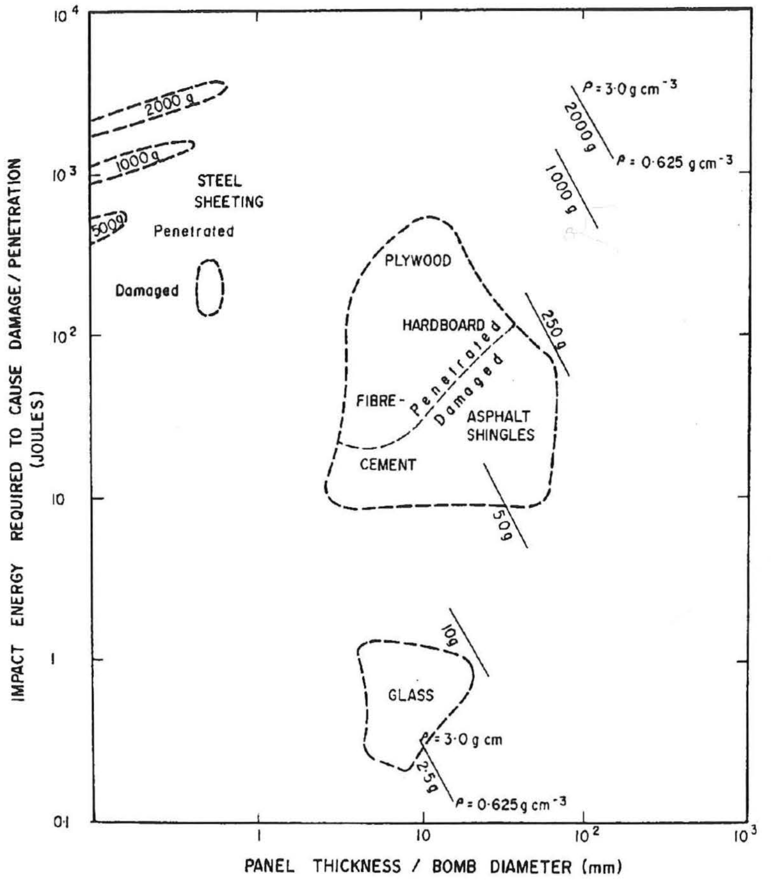


Figure 5.3 The relationship between volcanic bomb size, density and impact energy and the damage caused to a range of building materials. (Blong, 1981, p 407)

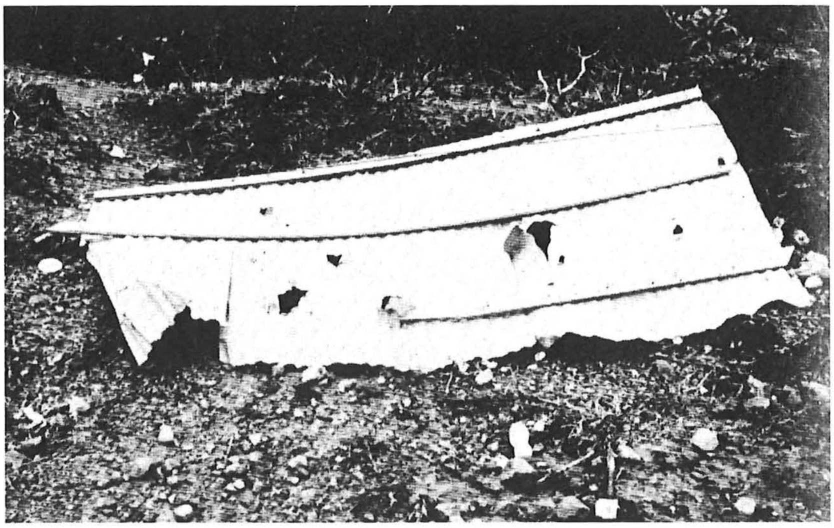


Figure 5.4 Roofing iron pierced by volcanic bombs, Soufriere de Guadeloupe. (Blong, 1984 p 206)

The risk to human life also depends on the impact energy of projectiles. Booth (1979) observes that 9 cm diameter scoria from the 1973 eruption of Eldjfell (Heimay) caused no discomfort provided padded clothing and a helmet were worn. However he also notes that in 1974 an eruption of Etna caused severe lacerations to spectators when scoria under 8 cm diameter struck them. Furthermore in 1971 5 cm fragments penetrated fiberglass helmets left out overnight on the volcano (Booth, 1979). Since the density of 1886 fragments from Tarawera is above average, (Walker et al, 1984) it would be safer to assume that these smaller fragments pose a serious threat to the health of anyone caught out in the open during strombolian activity. Likewise stock left in the area would be at risk from ballistic ejecta.

During the 1886 eruption, scoria clasts over 64 mm in diameter fell at a distance of over 12 km to the southeast of the eruptive fissure (Walker et al., 1984). This area is extensively farmed, both farmhouses and other dwellings (including the settlement of Rerewhakaaitu) are found within range of projectiles of this size. Farmhouses are also situated at a distance of 7 km from the crater (on Tawa Road). Walker et al. (1984) found scoria clasts up to 74 mm diameter at this distance. 128 mm bombs were found as far as 6 km from the craters. Though less dense than the 2.5 g cm^{-3} quoted by Blong (1981; 1984), in ascertaining impact damage on roofing materials, they are of sufficient size to penetrate steel cladding materials. Projectiles this large will only threaten a few houses; those at the west end of Ash Pit Road, and some to the south east of Lake Rotomahana. To the east and south, almost all buildings between Rotoiti or Kaingaroa forests and the volcano will be at risk from ballistic impact damage. Bombs may penetrate cement tile roofs, and damage galvanized iron roofing. Windows will easily be broken by these impacts. The risk to human life will also be considerable - any person caught outside during a shower of bombs and scoria of this size will be at risk of death or maiming from the impact of these projectiles. Risk will diminish with distance from the vents, stock in fields along northern boundary road will have a reasonable chance of survival, whereas animals 3-4 kilometers closer will be more at risk of death/injury. The Spencer Road settlement along the western margin of Lake Tarawera will also be at risk, as areas of this settlement lie within 10 km of the Tarawera vent. Projectiles over 64 mm diameter may damage roofs, break windows and may severely injure people outdoors. Further away the Lake Okareka township will also be at risk from ballistic projectile impacts. Clasts will be smaller (up to approximately

32 mm) but they may still injure those outside, and break windows. Table 4.2 indicates maximum probable distances clasts will travel.

Ignition from projectiles

Fires affecting buildings may start directly from incandescent projectile impacts on houses, or from vegetation fires that spread to structures. These fires will only start in proximal areas, as clasts will cool the further they travel. Bombs may have started fires in Te Wairoa during the 1886 eruption (see chapter 4, p.67). They may do so again at similar distances from source.

Base surges

Houses at the west end of Ash Pit Road, at Waimangu and around Rotomahana Road are all within 3 km of the source of phreatomagmatic explosions from the Lake Rotomahana – Waimangu section of the Tarawera Vent Lineation. This puts them at extreme risk of complete destruction by pyroclastic base surges. No mitigation could be effected at this distance, surges will destroy any building in their path. Evacuation will therefore be the only possible option. Rerewhakaaitu settlement is situated just outside a 6 km radius of prospective vent locations, and therefore not as likely to be destroyed by base surges, though this is still a possibility. The town will still be at risk of inundation from thick deposits of lake-floor sediments carried by the eruption plume. Again evacuation will be necessary.

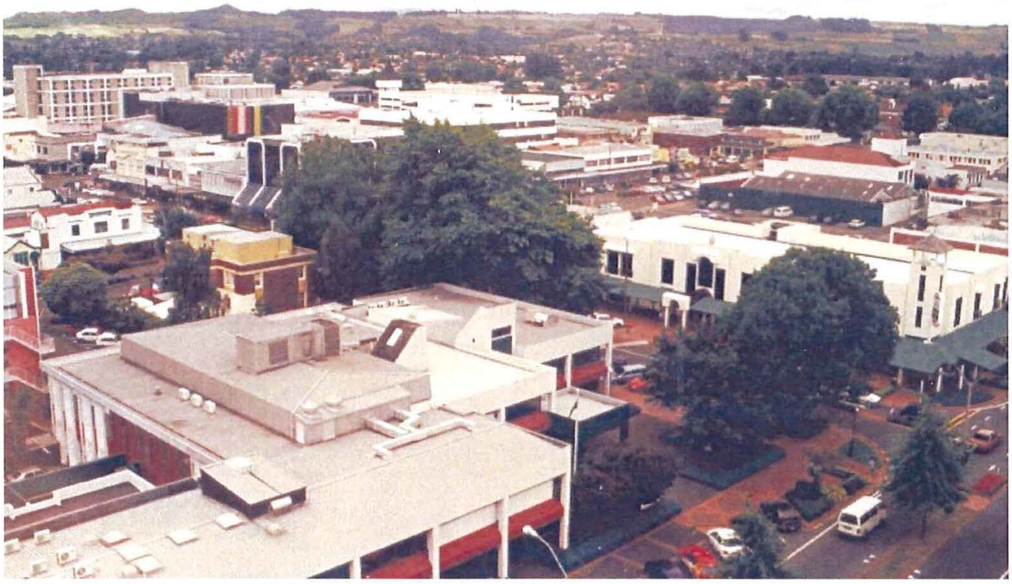
Medial / distal effects

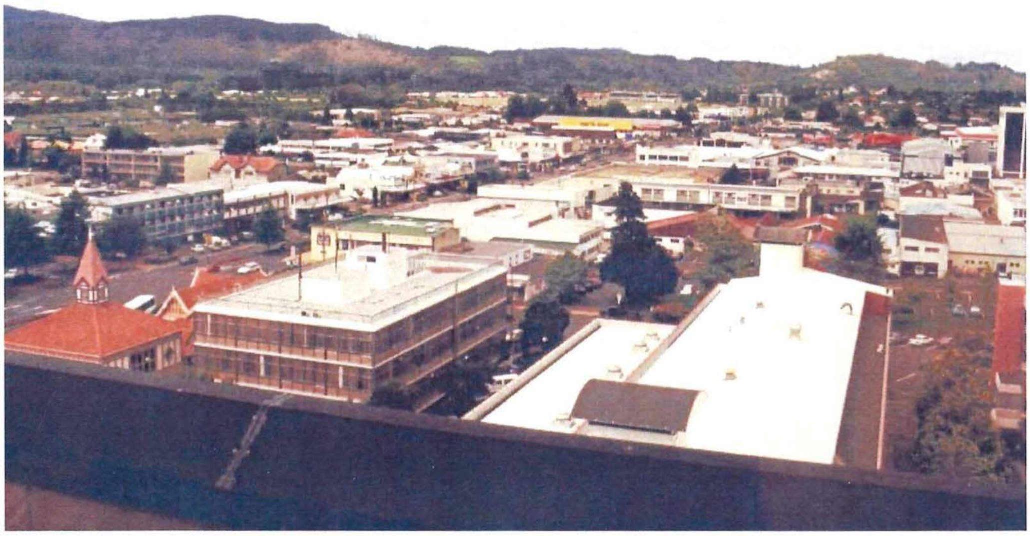
Tephra Loading

The effects of ashfall on buildings depends on the thickness of ash, the density of that ash and whether it is wet or dry, the building's orientation, wind direction/speed and the construction of the building. This last parameter includes the pitch of the roof, cladding materials, structural support of roof and walls, and the span of the roof. Minor effects such as corrosion of paintwork are dependant of the chemistry and volatile content of the ash.

During an 1886 type eruption of Tarawera, it is inevitable that tephra loading on structures will affect some communities. Which communities will depend on the wind direction; with an easterly wind blowing, up to 30 cm of ash may fall on eastern suburbs of Rotorua, a southwesterly wind would have this effect on Kawerau. This thickness of ash will not remain on all roofs; pitched roofs may shed some of the load. The amount will depend on the actual pitch and the cladding material of the roof. There is a lower friction coefficient for galvanized iron than concrete tiles for example, pitched iron roofs will thus shed ash more readily than tile roofs. Most house roofs in the Bay of Plenty are pitched to some degree, and both concrete tiles and galvanized iron are common. Commercial and industrial premises on the other hand often have very low pitch angles, or even completely flat roofs. This is certainly true of Rotorua, buildings in both the central business district and industrial areas such as Ngapuna have mainly flat roofs, as illustrated in figures 5.5 – 5.7. These are unlikely to shed much ash at all. The same applies to large retail premises, like supermarkets and warehouse distribution outlets.

Figure 5.5 Ngapuna, Rotorua. Note the many large span low pitched or flat roofs of the industrial area. (Photograph courtesy of Rotorua District Council)





Figures 5.6 (above) and 5.7. Central Rotorua, illustrating many flat and low pitched roofs in the CBD

More steeply pitched roofs will stand up to live loads better than flatter roofs (Blong, 1981). For example during the 1991 eruption of Pinatubo, buildings at Clark Air Base received ~150 mm of tephra. Residential houses with moderately pitched roofs (~33^{O}) remained relatively undamaged (even when ash was not readily shed from roofs), while a wide-span aircraft hanger with a gently curved roof collapsed (Johnston, 1997). Conversely, drifts (of snow at least) can sometimes accumulate to a larger degree on pitched roofs, and create a greater load (Blong, 1981). As a rule pitched roofs will however prove to be more robust than flat roofs.

Thicknesses of ash calculated to fall in any given area are an average thickness – they suppose a lack of wind. This is very unlikely as even on comparatively still days some wind will exist. Consequently loading will not occur evenly, and drifts will form. These will create even more loading problems as the load is spread unevenly. Figure 5.8 illustrates the distribution of tephra loads on roof types when influenced by wind.

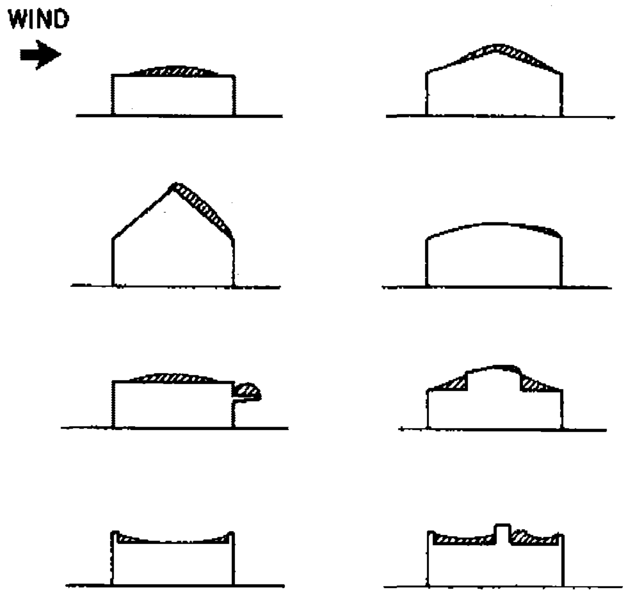


Figure 5.8 Distribution of tephra loads on roof types when influenced by wind (Blong, 1981, p415)

Importantly, projections such as chimneys and parapets can create areas of aerodynamic shade, causing drifts to form. This may result in loads two times that of the ground load. Furthermore when low roofs are present below larger higher roofs loads as much as 3 times the ground load can exist on the lower roof. This is compounded even further if tephra slides off higher roofs onto lower roofs, as impact loads then apply (Blong, 1981). A

30 cm thickness of ash may therefore be translated into as much as a 90 cm load on lower roofs, causing collapse in almost all cases.

To determine loading the following equation is used: *(from Johnston, 1997)*

$$L = dpg/1000$$

Where: L is volcanic ash load (kPa)
d is ash depth (m)
p is ash density (kg m^{-3})
g is gravitational acceleration (9.8 m s^{-2})

Using the bulk density of 1600 kg m^{-3} and a rounded down wet density of 2000 kg m^{-3} (given in chapter 4), expected maximum values for loading (in kPa) from future basaltic activity at Tarawera are given in table 5.4. These are based on the maximum distance from source of 1886 isopachs.

Table 5.4 Maximum possible tephra loading under 1886 conditions by distance from source

Distance from Source	Max. possible tephra thickness	Loading Dry tephra, no wind	Max. loading Dry tephra with drifts	Loading Wet tephra, no drifts	Max. Loading Wet tephra, with drifts
10 km	900 mm	14.1 kPa	28.2 kPa	17.6 kPa	35.3 kPa
12 km	500 mm	7.8 kPa	15.7 kPa	9.8 kPa	19.6 kPa
25 km	300 mm	4.7 kPa	9.4 kPa	5.9 kPa	11.8 kPa
35 km	150 mm	2.4 kPa	4.7 kPa	2.9 kPa	5.9 kPa
50 km	75 mm	1.2 kPa	2.4 kPa	1.5 kPa	2.9 kPa

30 cm of dry tephra will thus exert a load of 4.7kPa assuming no wind and even distribution. 30 cm of fully saturated wet ash will exert a much heavier load of 5.9kPa. None of the Bay of Plenty area is subject to New Zealand snow loading codes, however roofs in New Zealand are usually designed for about 2.5kPa, with a safety factor of 1.5, therefore total capable capacity is typically 4kPa (Dr. J. Mander, *pers. comm.*, 2003). Even

with these figures there will be a lognormal distribution of their validity (+100% -50%). Therefore even though 4.7 kPa exceeds the load bearing capacity specified for roofs, it does not follow that all roofs will collapse. With similar loads (4.5-6.0 kPa) on houses during the 1994 Rabaul eruption, less than 50% of roofs collapsed (Blong & McKee, 1995). However the redistribution of ash by wind will create drifts, and some roofs will have areas with up to twice the ground load, i.e. 9.4 kPa. This creates a much larger demand on roofs, which will in almost all cases cause failure. Similarly the 5.9 kPa load expected from 30 cm of wet ash will cause more failures than dry ash. As water acts as a dust palliative on ash, wet ash is unlikely to form drifts. However pre-existing drifts that are subsequently wet by rainfall may result in loads that are considerably more than the average ground load, as up to almost 500 litres of water per cubic metre of ash is absorbed. A fully saturated 60 cm drift would thus exert a load of 11.8 kPa, an amount which exceeds the design load of most roofs by almost 8kPa. Collapse would be almost inevitable – even if the roof remained intact walls would be likely to fail. It is therefore necessary to quickly clean roofs that do survive after an ashfall.

If 30 cm of ash falls on Rotorua or Kawerau, many buildings will collapse under the load of ash. The 4kPa standard that most roofs are built to, will be equal to about 250 mm of dry tephra, or 200 mm of saturated tephra. An average deposit of this much will result in damage, especially to flat or slightly inclined large-span roofs. Where drifts occur damage will be exacerbated, but most houses will survive largely intact. However even buildings whose roofs cope with the load of tephra will sustain damage.

Spoutings/gutterings are a common casualty during even light ashfalls; the recent Etna eruption was no exception, as light ashfalls of <30 mm in towns such as Zafferana and Nicolosi resulted in ash being washed into roof gutterings on many houses, blocking them up and causing collapse. Several spoutings on homes in New Zealand experienced this during the 1995 – 96 eruptions of Ruapehu (Johnston et al., 2000a). The removal of spoutings on houses would be advisable prior to any evacuation; as well as minimizing damage to the spoutings themselves, tephra will be more able to slide off pitched roofs without a buildup on the edge of the roof initially stabilizing the tephra accumulating further up. Dry tephra penetrating roofs and creating drifts inside the ceiling cavity is another hazard that may affect houses that otherwise survive the tephra loading (Blong, 1984). Ceilings will quickly collapse under the weight of tephra drifts. Tiled roofs may be more susceptible to this than iron roofs, owing to the greater number of spaces for tephra to penetrate.

Closer to Tarawera, buildings downwind of ash may receive considerable amounts of tephra, and possibly mud. The Spencer Road community is spread out along the east coast of Lake Tarawera, and as such some parts of the settlement are closer to the volcano than others. At this range (~ 10 km) ash thicknesses will differ considerably. Those properties at the south end are also closer to Rotomahana, and may therefore receive deposits of mud as well as ash. Te Wairoa received ~80 cm of ash and mud in 1886, with drifts of over 2 metres. This amount of ash and mud may well be emplaced here again, thicknesses will be similar on the Ohinetekura point and Rangiuru Bay sections of Spencer Road, a region with over 200 permanent dwellings and holiday homes. Even without drifts creating excess loading, 80 cm of ash, lapilli and mud will weigh over 1300 and up to 1450 kg m^{-3} depending on the mud-ash ratio. This equates to 12.75 – 14.2 kPa, an amount that will completely destroy most buildings in the area. To the south of Tarawera, Rerewhakaaitu settlement and all other buildings north of Northern Boundary Road are also within range of this kind of deposit. Much of this area is also at risk from base surges, and not much is expected to survive an eruption in the event of ashfall and surges traveling in this direction.

In eruptions with a duration of days or longer, ash may be manually removed from rooftops before tephra loads exceed the load-bearing capacity of the roofs. This would prove to be more difficult in the event of an 1886 type eruption, as it would accumulate within a few hours. Buildings could be protected to some degree if cleaning was undertaking during the ashfall, helping key infrastructure survive. In Rotorua and Kawerau, the impact of ash and lapilli would not be sufficient to wound people outside cleaning roofs. However there would still be a risk of injury that would need to be taken into account. Injuries are commonly reported when cleaning ash off roofs is undertaken, for example falls from ladders and roofs. The risk is increased during an ashfall; if cleaning is not preformed quickly enough the roof may collapse underneath the cleaners. Moreover in a heavy ashfall (as is expected from Tarawera), it will be dark, whether it is day or night. The urgency required in performing these tasks during an eruption would probably result in less safety precautions being taken. For example most buildings in the CBD front directly onto footpaths – anyone passing below may be exposed to large amounts of tephra being swept off roofs. Problems with finding available staff to clean ash from the roofs of commercial, industrial or key infrastructure premises may also be had, as local staff will be more likely to want to protect their homes and families than their workplace – assuming no evacuation has taken place.

5.2.3 Electrical distribution networks

The importance of the integrity of electrical supplies is heightened by the dependence on electricity of other essential lifelines, such as water supplies, wastewater reticulation and telecommunications. The susceptibility of electrical distribution networks to damage from volcanic ash is known from the experience of previous volcanic activity, both in New Zealand and overseas. For example on 17 June 1996 Rotorua experienced electricity blackouts as a resident hosed ash off a neighbouring roof onto a transformer at a local substation (Johnston et al., 2000a). A full description of the effects of volcanic ash on electrical distribution networks is given in Sarkinen and Wiitala (1981). That study specifically looked at those effects, using ash from the Mt. St. Helens eruptions of 1980. While only this one source of ash was used, results from the Sarkinen & Wiitala study are compatible with the effects of subsequent ashfalls on electrical distribution equipment. Tephra was found to be conductive only when wet, and more so when it was a finer grainsize (deposits thus have a higher surface area). Problems caused by volcanic ash occur as ash adheres to insulators on electrical equipment (transformers, lines etc). If the ash is damp, (which may occur if it is from a phreatomagmatic eruption, or if weather conditions dampen the ash), the conductivity becomes high enough to cause flashover. A flashover occurs as electricity jumps (arcs) from a conductor to earth, or from conductor to conductor (Transpower, 2003). This damages the insulators themselves, and the lines or transformers they were designed to protect. Subsequently power may be cut. The Sarkinen and Wiitala study also found that lower voltage insulation is generally more at risk of flashover than higher voltage, due to these insulators having smaller weather sheds. This study used andesitic ash from Mt. St. Helens, and ensuing available documentation of eruptions affecting electricity networks has all been of andesitic ash. However flashover is also experienced in dry dusty areas devoid of volcanic ash as sediment builds up on power lines and insulators. After several months of dusty dry conditions in Western Australia the first rain of autumn/winter often dampens wind-blown fine sediment on electrical equipment, causing flashover and small fires to start on wooden power poles (D. Richards, *pers. comm.*, May 2003). This demonstrates that it is more the capacity for holding water close to the insulators than the presence of volatiles associated with the ash itself that causes flashover. In terms of the effects on electrical components, basaltic ash is therefore expected to act in a similar way to the andesitic tephras studied from past eruptions.

The chances of flashover occurring will be highest if light rain falls during or after the eruption. Heavy rain is more likely to wash most of the ash off electrical transmission equipment, whereas light rain or drizzle will wet the ash but not dislodge it (Heiken et al., 1995). Ash from a wetter style of eruption, such as might occur from the Rotomahana area, will disperse wet ash and sticky mud over a wide area, potentially causing more harm to electrical systems than the ash erupted from a purely magmatic source, due to the higher water content.

As well as tephra causing flashover it is possible that the weight of ash on transmission lines will bring them down. This is even more applicable to the mud erupted in phreatomagmatic eruptive styles, as it is sticky and thus has a greater likelihood of adhering to lines.

Another hazard likely to effect electrical distribution networks does not actually result directly from ashfall, but from atmospheric electrical disturbances associated with the eruption. Lightning strikes are commonly associated with volcanic eruptions, and the Tarawera 1886 eruption was no exception. Many telegraph lines and poles were struck by lightning, cutting communication links. Strikes such as these (on power poles) also occurred during the 1980 Mt. St. Helens eruptions, and the May 1924 Kilauea eruption, when 21 consecutive poles were hit (Blong, 1984). These lightning strikes may also cause pole fires and damage to substations.

The effects of volcanic ash on electrical distribution networks has been experienced by Transpower staff in the past, during the 1995 and 1996 eruptions of Ruapehu. Mitigation of ash induced flashover amounts to cleaning ash off affected insulators, which was performed during those eruptions by Transpower staff. Water blasters at approximately 1500 psi were used to quickly clean off ash, manual cleaning using a dry cloth was also employed, giving better results but taking much longer (Johnston, 1997). Similarly, fine wind-blown sediment is cleaned off power poles and lines by fire hoses at the end of summer in western Australia, to reduce the chances of flashover from build-up of fine sand over about four-months without rain (D. Richards, *pers. comm.*, 2003).

Electrical Distribution Networks in The Bay of Plenty Region

Included within the area subject to ashfall from Tarawera are four power stations, as well as substations, some of which are controlled by national grid operators (Transpower), and others by local electricity supply companies. Transmission lines in the area are a mixture of both high and low voltage systems. Figure 5.9 details electrical generation facilities, substations and transmission lines.

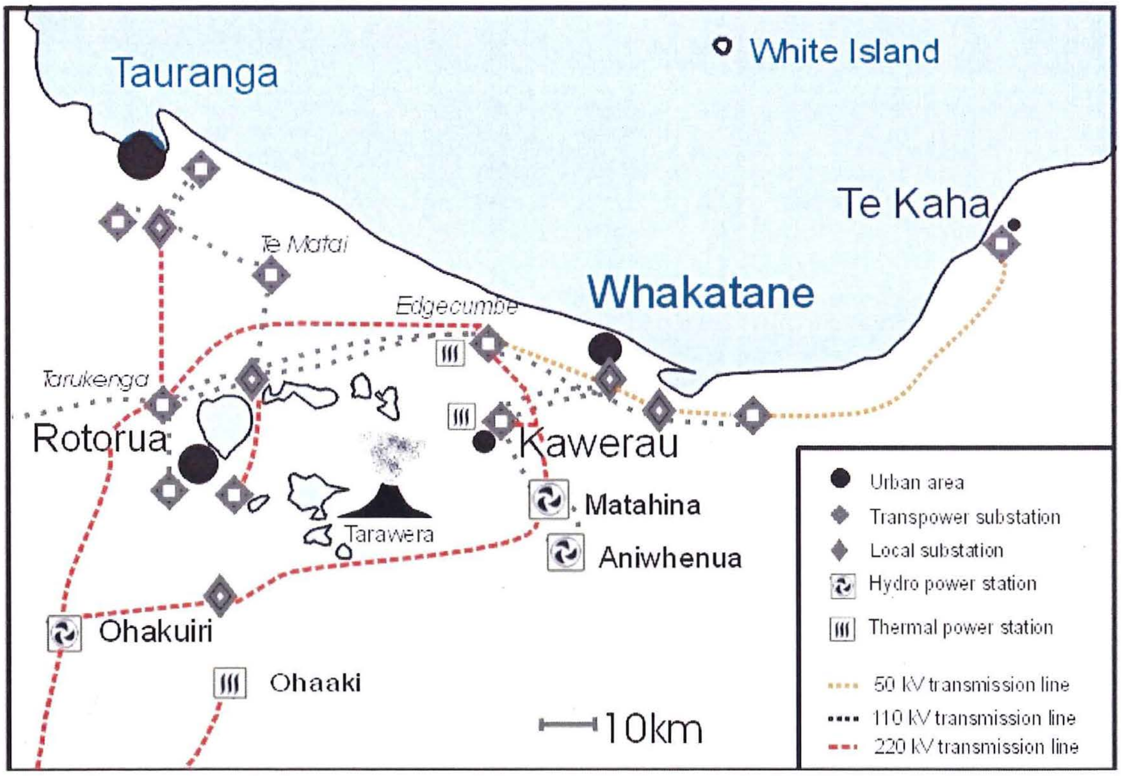


Figure 5.9 Electrical generation facilities, substations and transmission lines in the Bay of Plenty

Substations and Lines

Damage to substations will occur in part due to the same reason that Transmission lines will fail – flashover from conductive ash on insulators, but in this case on the insulators on feeder cables and transformers. In turn transformer fuses will be blown, again causing power outages. Lightning strikes may also damage substations. Protection and metering equipment in control rooms may also be at risk from building collapse under heavy tephra loading. The Edgecumbe Transpower substation is a vital link for the eastern Bay of Plenty, as it provides four local substations (Whakatane, Ohope, Station Road and Edgecumbe) with power from the national grid (Johnston, 1997). This substation also connects the Aniwhenua and Matahina hydro power stations to the national grid in the Bay of Plenty. 220kV lines provide an additional link to the national grid south of these hydro stations. However this link is the most vulnerable part of the electrical distribution network in the Bay of Plenty. A 13 km length of transmission lines passes within 6 km of the Lake Rotomahana-Waimangu section of the Tarawera Vent Lineation, at one point coming within 2 km of Waimangu. This whole length is at risk of being completely destroyed by base surges. Further lines connect the Bay of Plenty to the rest of the national grid through Tarukenga, north of Rotorua. Those lines pass within 24 km of Lake Rotomahana, and are thus not at risk of damage from surges, but may still be affected by ashfall. The Tarukenga substation may also be affected. It is 35 km from Tarawera Volcano, and may thus be subject to up to 150 mm of tephra, certainly enough to cause flashover. The 220 kV transmission lines that supply Tauranga also connect to the Tarukenga substation. In the event of damage to Tarukenga, Tauranga would still be connected to the national grid via the Te Matai substation, but only with 110kV lines, which may also be subject to damage from ashfall. However even this substation requires a link to either Tarukenga or Edgecumbe to remain operational. Should Tarukenga and Edgecumbe both be damaged sufficiently to cut power, the entire Bay of Plenty region, including Rotorua, Tauranga and Whakatane would be without power.

Connections west of Opotiki through to Te Kaha are reliant on a low voltage (50kV) supply line, which will be especially susceptible to flashover from volcanic ash coating insulators. Although more distal, sufficient quantities of fine ash to cause arcing may adhere to insulators. Whakatane is connected by both 50kV and 110kV lines to the

Edgecumbe substation, as opposed to the more robust (in terms of the effects of tephra) higher voltage 220kV lines that connect most of the main centres.

Power Stations

Power stations located in the Bay of Plenty region include both hydro and geothermal stations, and a cogeneration gas-fired turbine at Edgecumbe. The plant at Edgecumbe supplies the Anchor dairy-processing factory with up to 10MW of power, the surplus of which is sold to Bay of Plenty Electricity (BoPE) to service domestic customers. Edgecumbe is about 35 km away from Tarawera Volcano. It received over 10 cm of ash during the 1886 eruption. This can be viewed as a maximum expected deposit from a basaltic eruption, as it was directly downwind from the Volcano. The turbines are housed indoors, and therefore should not be at risk from flashover. Flat or slightly pitched roofs exist on all of the main structures associated with the mill and power plant structures. These should be able to withstand a 10 cm deposit of dry ash, but if the roofs were not immediately cleaned they would run the risk of collapse as the tephra absorbed water, increasing the demand on the roof. This depth of deposit would probably result in the factory temporarily closing, due both to access problems, and a depleted workforce trying to cope with the effects of the eruption on their homes and families. Assuming minimal staff could reach the factory, power may be available from this plant in the event of power cuts from other supplies.

Closer to Tarawera Volcano, Kawerau Geothermal Station supplies the Tasman and Caxton pulp and paper mills with their energy requirements, with an output of around 6MW. This is derived from two geothermal plants, one on each side of the Tarawera River, adjacent to the mill (Todd Energy website). The proximity of the Kawerau power station to Tarawera Volcano (~20 km) puts it at high risk of damage from a future basaltic eruption. Like Edgecumbe, the Kawerau area was directly downwind from Tarawera in 1886. This area received about 30 cm of ash during the eruption. This amount will put the plant at high risk of damage from tephra loading on structures, which may cause collapse. Flat roofs on most buildings associated with the mill and power station will exacerbate the loading problems. As well as potential damage directly occurring from roof debris landing on machinery, the tephra that was responsible for the collapse will then inundate the space below.

Lahars travelling down the Tarawera River will also threaten the power station and mill, as they are situated on its banks. These are most likely to occur after an eruption, as a result of the collapse of tephra dams. Close monitoring of the river will be necessary to stop large accumulations of volcanic debris from blocking the river or lake outlet, as occurred in 1904 (see chapter 2). Large lahars will not only destroy the power plants and mill, but may inundate significant areas of the plains around the river.

Located less than 30 km to the east and southeast respectively of Tarawera Volcano are the hydro power stations of Matahina and Aniwhenua, on the Rangitaiki River.

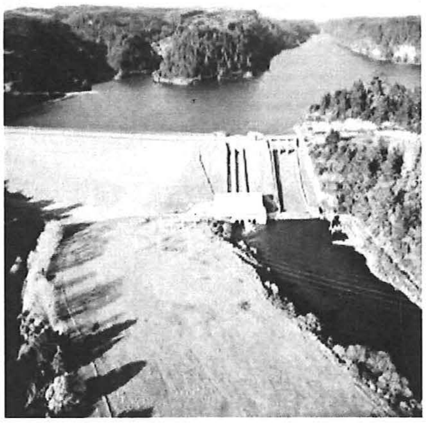


Figure 5.10 Matahina hydro station (photograph from Trustpower)

The combined output of these two stations is almost 100MW, making them much more important to local energy requirements than the Kawerau and Edgecumbe plants. They are situated a similar distance from source than the Kawerau plant. Therefore in a worst-case scenario, with westerly winds blowing ash directly towards either one, tephra should again not exceed an average thickness of ~30 cm. While the dams themselves will cope with tephra loading, the powerhouse roofs may collapse, damaging machinery. Transmission lines may fail due to flashover. Furthermore Aniwhenua powerhouse and Lake Aniwhenua dam control gates are remotely controlled from the BoPE main office in Whakatane (Todd energy website). Should phone lines be cut off, this method of control will be curtailed. The computers used to control these facilities may also be subject to damage or destruction in the event of tephra collapsing control buildings. A study by Gordon (2002) on the effects of volcanic ash on computers concluded that in the short term at least, computers were resilient to volcanic ash, main components such as hard drives were adequately sealed so as to prevent dust (and ash) infiltration. Keyboards and floppy disks are more vulnerable than internal hardware, but inexpensive to replace. Wet conductive ash is more likely to produce short-circuting, however wet ash will not be as mobile as dry ash, and is less likely to infiltrate buildings, then computers. In the event of building collapse, assuming falling debris does not damage computers, it is more likely that any ensuing rain will damage computers more than the effects of the ash itself. The control systems in place at Aniwhenua should therefore survive if the building housing them does, but communications with the Whakatane control centre may be disrupted.

The effects of ash on the components of hydroelectric stations was highlighted during the Ruapehu 1995 eruptions, as andesitic ash passed through the Rangipo Power Station, damaging turbines and auxiliary systems. During the seven months from September 1995 to April 1996 it was estimated that the equivalent wear of 15 years station life occurred (Malcolm & Van Rossen, 1997). Almost \$6.3 million had to be spent on rehabilitation. In April 1996 the two turbines were shut down because of excess wear of runners and seals, guide vanes, cheek plates and guide vane stem bearings and seals (Malcolm & Van Rossen, 1997). However there is one important difference between the Rangipo hydroelectric station and the Aniwhenua & Matahina power stations. Whereas Rangipo is a run-of-river scheme, fed directly by the Tongariro River, both Matahina and Aniwhenua stations use dams to create lakes from which water is sourced. The slow moving water in these lakes will help to settle out suspended ash before water passes through the turbines. Given possible volumes of ash in the catchment area (~20 cm thickness), a large amount of sediment will still pass through the systems. This alone will not immediately stop the plants from working, but may cause gradual damage similar to that experienced at Rangipo in 1995-1996. This is assuming that operators Trustpower (Matahina) and BoPE (Aniwhenua) are still willing to keep the plants operating with the additional sediment load. The additional problem of siltation in the lake may cause long-term problems for the dams, reducing the capacity of the hydro lakes, and thus the capacity for generation in drier times.

Conversely these power stations will be able to supply the Bay of Plenty with (some) electricity in the event of winds blowing from the east or southeast during an eruption. Should this occur there is a high likelihood that tephra dispersed towards Rotorua or

Tauranga would cause power cuts by damaging substations and transmission lines to the west of Tarawera Volcano. There may be dependency on these power stations for some time if the eruption brings down many power lines in the Bay of Plenty – enough replacement line to repair all damaged transmission lines may take time to acquire.

5.2.4 Water supplies

Water supplies may be affected for all inhabited areas that are subject to ashfall. Effects will be worse in areas using rivers or lakes for water supplies than for spring fed supplies. Water tanks fed by roof run-off will essentially be rendered useless until ash is cleaned off rooftops. Siltation within the tanks will occur as ash is washed into them from gutterings, and they should therefore be disconnected in the event of an eruption. Furthermore even moderate ashfalls may result in the destruction of roof gutterings or spoutings as heavy ash is washed into them and overloads the brackets holding them up. Small rural communities which obtain water by this method may need to be supplied by water tankers in the event of an eruption until repairs can be made. In some cases access problems due to road closures may result in proximal settlements having to be temporarily evacuated.

Water supplies in major urban areas

Rotorua

Although in a worst-case scenario Rotorua may be subjected to large amounts of volcanic ash (~ 30 cm), the Rotorua area's water supplies are largely spring fed, and should therefore remain essentially free of an influx of tephra. A deposit of this much ash would likely result in the evacuation of most residents, however water supplies would still be required for those that remained, and for clean-up operations. Lighter ashfalls (millimetres to centimetres) would not result in many evacuations (other than those who left voluntarily). In this situation demand for water would most likely exceed normal demand.

The central urban area of Rotorua is supplied from the Karamu-Takina Springs. Water is then pumped via the Matipo and Utuhina pump stations to reservoirs. Reservoir capacity is 32,000 m^3 and average daily water demand was 23,572 m^3 in the year 2000. (Peak demand was 36,300 m^3). In the event of water supplies stopping, Rotorua has less than 36 hours supply under normal demand. This source supplies approximately 43400 people. Problems more likely to affect the water supply are a lack of power to work the pump stations. Two electric pumps that service the central Rotorua area (Matipo and Utuhina) are assisted by 3 booster stations (Pukehangi, Thomas Cr and Tihi-O-Tonga). This system supplies 15,500 connections through a total of 360 km of pipes. Should the electricity fail, so will most of the water supply. Only the Utuhina pump has a backup diesel generator (P. Cooper, *pers. comm.*,. 2003). This backup generator will only supply minimal water. The water supply has temporarily failed in the past due to volcanic ash affecting electricity supplies - during the 1995–1996 Ruapehu eruptions. A resident washing ash into a power transformer caused a power failure, stopping the water pumps. A hosing ban was imposed until power could be reconnected, as Rotorua almost ran out of water (Johnston et al., 2000a). The Utuhina backup pump existed at that time, but could not keep up with demand for water. Other problems may be related to ashfall directly affecting the pumps themselves, either through infiltration into electrical equipment at pumping stations, or possibly through the collapse of roofs of pumping sheds in the event of heavy ashfall (see section 5.2.2 on building damage). Collapse of these structures may cause damage to the pumps themselves. Eastern suburbs and Okareka supplies are sourced from springs in Whaka Forest, Ngongotaha from the Taniwha spring. The vulnerability of these supplies to ashfall is similar to the central area, except that the eastern suburbs may receive more ash than the central urban area and Ngongotaha less, owing to their respective proximities to Tarawera. While the subterranean supplies are not expected to be directly affected by ashfall, earth movement as a result of volcanic earthquakes may affect subsurface hydrology, and thus springs. Implications are that water supplies could be cut off, or flow reduced. This is more applicable to areas closer to the volcano, and less likely to affect Rotorua, but is a possibility that needs to be considered.

Though most water supplies in the Rotorua area are sourced from springs or bores, some smaller water supplies are from surface water. The Lake Rotoma settlement takes its water from the lake itself. A storage reservoir of 220 m^3 supplies an average of 71 m^3 of water per day to a total of 125 properties (Rotorua District Council, 2003). Heavy ashfalls in the area would result in siltation of the lake, which may in turn damage pumps and contaminate water supplies. Depending on volatile content of the ash, the pH may decrease in the lake waters. Fine suspended ash components in the water would also make drinking water cloudy. Current treatment of Rotoma water comprises solely of light chlorination, which would not remedy any of these effects. However in an 1886 type scenario the community at Rotoma (which is situated around the southern side of the lake) may be inundated with over 30 cm of tephra. This volume of ash may if wet, put a load on buildings of over 600 kg m^2 (5.9 kPa), certainly enough to damage buildings and collapse roofs. It is inevitable that this volume of ash would result in the evacuation of this community. Not only would buildings be destroyed, roads would also be closed, and the lack of facilities in the immediate area would isolate residents without a supply of food or medical attention. Light ashfalls that did not result in evacuation would only be expected to affect the water supply briefly, residents may have to temporarily rely on bottled water for drinking.

Tauranga

Tauranga itself will probably be subject to only light basaltic ashfall (a few millimetres fell in 1886), up to 5 cm in a worst-case scenario (assuming a southeast wind). While it is approximately 65 km from Tarawera Volcano, the catchment area for Tauranga's water supply is about 12-15 km closer, which may be subject to heavier ashfall in the event of an eruption. The Tautau and Waiorohi streams supply the city with water. In turn they are fed by springs from a large aquifer in the foothills of the Kaimai ranges. The headwaters of the two streams are situated approximately 50 km northwest of Tarawera, the streams flow away from the volcano, towards Tauranga. The Tautau stream supplies the Joyce Road water treatment plant (WTP) with up to 37,000 m^3 of water per day, the Waiorohi supplies the Oropi plant with 30,000 m^3 per day (Tauranga District Council, 2003). Distances from the springs to raw water pumps vary from 2000 to 5000m, as there are numerous springs (B. Everitt, *pers. comm.*, 2003). While the aquifer will not be affected by an eruption of Tarawera Volcano, the streams will be; ash falling on the catchment area between the springs and the pumping stations may result in massive amounts of siltation in the river, especially as rain during or after ash deposition washes ash from the catchment into the streams. Landslips in the Waiorohi stream have in the past caused major problems for the Oropi pump station and treatment plants, as the sediment load carried by the stream has resulted in large influxes of silt and ash (from past eruptions in TVZ). This has caused the plant to shut down on one occasion (Tauranga District Council, 2003). However the Oropi

WTP has in the past used a flashmixer to mix alum, lime and water before filtration through sand, and then chlorination. Colloidal material (mostly tephra) has been responsible for the damage. A recent upgrade of the Oropi WTP to a microfiltration treatment plant has made it more resistant to sediment influx. Between the stream and the pump intake, Oropi uses a sediment-settling basin to minimise sediment input. This is followed by a 14 m x 20 m treatment sedimentation tank, and a 3 mm screen before the 0.2μm filters. The Joyce Road WTP also uses microfiltration to clean water (plus a small amount of chemicals). Water is first passed through screens with 3-5 mm holes to stop leaves and large objects. It then travels through a 25m diameter raw water holding tank and a 0.5 mm screen before entering raw water pumps, and eventually the microfilters (B. Everitt, *pers. comm.*, 2003). In this way sediment input is minimised. However some tephra will still reach the microfilters, especially when the streams carry high sediment loads. Current procedure is to cease pumping when turbidity exceeds 500 NTU (Nephelometric Turbidity Units) (B. Everitt, *pers. comm.*, 2003). (New Zealand drinking water standards are for water to be clearer than 0.1 NTU). Despite ash entering the system, particles that get through the sedimentation basins and screens are not expected to adversely affect the membranes - they are designed to cope with filtering sediment, and do cope with the influx of existing rhyolitic ash from deposits in the area. However as the sediment load is increased, the capacity of the plants is reduced. This is a function of the solids loading capacity of the membranes. As more particles are trapped by the membranes, less water is able to pass through. A reduced amount of water will therefore be available for supply. Should turbidity in either stream exceed the 500 NTU threshold, shutting down one of the plants, water supplies will be reduced further. Fortunately supplies are able to be diverted from the Joyce WTP in these situations.

In the eventuality of high siltation in the streams forcing both plants to temporarily close, Tauranga will be able to temporarily manage to supply essential water to residents, with the aid of water restrictions to preserve reservoir stores. Current storage capacities for treated water in the Tauranga area (including Mount Maunganui) are 68,650 m^3. Water use in the area currently averages between 30,000 and 35,000 m^3 per day, however in summer this has been up to 57,000 m^3 per day (B. Everitt, *pers. comm.*, 2003). Essentially Tauranga has therefore about 2 days (under normal demand) of water stored. Water use restrictions could be put in place in a civil emergency, but basic requirements would still put high demand on the reservoirs. Moreover water demand usually increases in times of ashfall, as residents use hoses to clean their property (Johnston et al., 2000a). Bringing water in by tankers to supply a city of over 90,000 is not feasible. Therefore it is essential that pumps are turned off during high sediment flow in the supply streams. As the suspended load decreased pumping may then be reinstated to replenish reservoirs. Regular emptying of the Oropi WTP sediment settling tanks and the Joyce Road WTP raw water holding tank will be required to avoid excessive build-up of fine tephra. Provided the usual procedures are followed, Tauranga's water supply is expected to be robust enough to survive ashfall from Tarawera Volcano. Often water supplies are reliant on the integrity of electricity supplies to keep pumps working. However dependence on electricity is not an issue for water supplies in Tauranga. All pump stations and treatment plants are equipped with permanent diesel standby generators that automatically start in the event of power failure. The distance of Tauranga from Tarawera Volcano makes it susceptible only to distal hazards such as ashfall. Tephra is not thought to be likely to be thick enough to severely damage buildings in this area (at worst about 3 cm), water supplies are therefore the most important lifeline to be at risk of damage from Tarawera Volcano. However the water treatment plant infrastructure, and methods employed by Tauranga District Council at present should cope with a basaltic eruption of Tarawera.

Whakatane

Like Tauranga, Whakatane's water supply is fed from a river. In this case water is sourced from the Whakatane River, just upstream from the town. This source also supplies almost 1500 connections in Ohope and Otarawaiwere. Water is pumped through a single silt trap and clarifier before being filtered through sand, and then chemically treated (Johnston, 1997). A pre-settlement tank is expected to be installed during upgrades planned to take effect in 5-6 years (S. Selvaratnam, *pers. comm.*, 2003). Any west or southwest wind during an eruption of Tarawera will result in the parts of the catchment area of the Whakatane river being subjected to moderate tephra deposits of up to 10 cm average thickness. Much of this will be washed into the Whakatane River in the event of rain, resulting in high levels of turbidity. Should pumps continue to be operated in these conditions, a large influx of ash into the system would quickly damage and/or block pumps and treatment facilities. While the treatment facility still functioned, fine colloidal material would not be adequately filtered and storage reservoirs would be contaminated by cloudy, possibly slightly acidic water. In the event of pumps being turned off before turbidity levels were too high, Whakatane would still have to rely on what supplies were stored in reservoirs. Daily peak demand of water from the Whakatane River averages 11880m^3. Reservoir capacity is essentially 10,300 m^3 from the main reservoirs, plus a few hundred cubic metres from small reservoirs above the Melville subdivision (Whakatane District Council). This capacity represents less than one day of normal water supply. Immediate and severe water restrictions would therefore need to be emplaced in the event of an eruption affecting the water supply to prevent Whakatane running out of essential water. The same scenario applies to water supplies stopping because of electricity supplies being cut off as Whakatane currently has no alternative backup generators. The district council plans to install a single 200kV diesel backup generator in 2004 (S. Selvaratnam, *pers. comm.* 2003).

Kawerau

Water supplies in Kawerau are drawn from covered springs and should thus prove to be unaffected directly by tephra fall. However the pumps for the water supply will still be vulnerable to power cuts if the electricity supply is compromised.

"The Plains" Water Supply

The area bounded by State Highway 30, the Tarawera and Whakatane rivers and the coast is supplied by the Plains Water Supply. Edgecumbe and Awakeri are included in this supply. Water is derived from an artesian spring, adjacent to Braemar road, near the Tarawera River (Whakatane District Council, 2003). Ash influx is not likely to affect this supply given the subterranean source, however the pipeline travels across the Tarawera River on its own specially constructed bridge. This bridge may be at risk of being washed away in the event of lahars travelling down the Tarawera River after an eruption. A backup pump and bores near Otakiri may provide emergency water supplies should this happen, however it is possible that lahars may be large enough to affect this system too. Again this water supply is dependent on the integrity of electricity supplies.

5.2.5 Wastewater

Wastewater infrastructure, referring to stormwater drains, sewage pipes and sewage works will be adversely affected by any influx of volcanic ash. In some cases stormwater drains connect into sewage pipes, and stormwater thus passes through wastewater treatment plants before discharge. In this situation, ash is easily washed off roads and roofs into stormwater drains, and then into the wastewater treatment facilities. It can block up drains, damage pumps, filters, clarifiers and solid removal equipment. Biofilters may be stripped of growth and excessive wear on pumps and pumping components is likely (Blong, 1984). Settlement ponds will accumulate more sediment than they can handle. These precede oxidation ponds, to take solid matter out of sewage. However tephra will not be adequately filtered out and ash will make its way into the oxidation ponds, inhibiting biological oxidation. Airborne tephra falling directly into oxidation ponds will make this even worse. In these eventualities, raw sewage may end up being pumped directly into the sea/river. Blockages and damage in the waste treatment system in Yakima after the Mt. St. Helens eruption in 1980 resulted in raw sewage having to be pumped directly into the Yakima River for a few days, bypassing the treatment plant until repairs and cleaning could take place (Blong, 1984). Effects expected from ashfall in the Bay of Plenty region on local sewage treatment plants are not expected to be quite as severe, as stormwater and sewage are not combined in any of the 3 main urban centres.

Sewage treatment plants

Rotorua

Wastewater and stormwater systems in Rotorua are kept separate. Stormwater is piped directly to waterways and to Lake Rotorua (Rotorua District Council, 2003). Both light and heavy ashfalls in Rotorua may result in tephra blocking drains, the severity defined by the amount of tephra that is allowed to enter the system – in turn partly dependent on how much is present. Sewage systems in Rotorua would be affected either directly via ashfall on oxidation ponds, or by electricity cuts stopping any/all of the 53 sewage pumping stations in Rotorua and Ngongotaha from working. Some sewage disposal in Rotorua takes place by spraying effluent in Whakawerawera forest. This would also cease without electricity to drive the pumps.

Tauranga

An influx of tephra is expected to cause blockages in Tauranga's stormwater drains. The worst-case scenario of ~5 cm of ashfall could cause substantial problems for drainage if it rains before roads and buildings are cleared of ash. Like Rotorua, sewage and stormwater are not interconnected in Tauranga, which will help sewage treatment facilities function after an ashfall. 101 wastewater pumping stations and 829 km of sewage pipeline exist in Tauranga (Tauranga District Council, 2003) they should remain unaffected, unless illegal connections from stormwater systems exist that may introduce tephra to the system. However airfall directly into the two treatment plants (Chapel Street and Te Maunga), will inhibit the biological oxidation processes used to treat raw sewage. Sewage that is not fully processed may end up being discharged from Tauranga's deep-sea effluent outfall pipeline. Consequently pumps used to do this may suffer from abrasion from tephra passing through them.

Whakatane

Whakatane's main problem with sewage processing may come from electricity outages, cutting power to the 13 electric pump stations. The 23-hectare oxidation pond will also suffer from an influx of airborne tephra, creating an anoxic environment and killing off the micro-organisms used to treat sewage. The lack of power to run pumps will not be as important to sewage reticulation as it may first appear – any power cuts will also have stopped the water supply from working. There will thus be little input of sewage to those systems after Whakatane has run out of water (reservoir storage is less than 24 hours under normal usage). Assuming power remains working or is reinstated, the effluent taken from the oxidation ponds is normally pumped to an outfall pipe that discharges the treated effluent 600 metres out to sea. The pump that performs this task will be subject to abrasion from tephra in these oxidation ponds, and may subsequently fail. Stormwater systems will be at risk from an inundation of tephra following rainfall, and causing blockages - which in turn cause localised flooding.

5.2.6 Telecommunications

Problems commonly affecting telecommunications during eruptions include atmospheric electrical interference of microwave and VHF or UHF radio signals, lightning strikes on repeater stations and poles carrying lines, exchange air-conditioning failing due to tephra blocking intake filters, the disruption of power supplies and tephra loading collapsing lines – or buildings in extreme cases. Overloading of networks as people check on neighbours and relatives can also cause temporary cuts to telephonic communications, this occurred in Yakima after the Mt. St. Helens eruption for example (Blong, 1984).

There is a high probability that radio, mobile phone and landline phone communications will be severely interfered with from atmospheric electrical disturbances during an eruption from Tarawera, while large volumes of tephra are present in the air. Although this does not always happen during eruptions it is a frequent occurrence, and the 1886 Tarawera eruption was no exception. Telegraph operators in both Maketu and Rotorua found transmission impossible during the eruption, though lines were still intact (see chapter 2). The phreatomagmatic activity expected from Rotomahana also increases the chance of electrical disturbances, due to the high conductivity associated with wet tephra. Backscattering of radio wave energy caused by ionised gaseous columns and lightning will disrupt most radio wavelengths, microwave frequencies are more likely to be attenuated by absorption of the signal in the ash cloud (Blong, 1984). Radio communication by civil defence authorities during an eruption will thus be compromised.

Not only will radio communications be affected, telephone communication in several towns will be disrupted because of electromagnetic disturbances. Four microwave repeater stations are located within a 30 km radius of Tarawera and Rotomahana. The closest one is situated on top of Mount Edgecumbe, the others are at Manawahe, on Ngongotaha (Rotorua) and in the Paeroa Range. Being situated on high ground they are all susceptible to damage from lightning strikes, the Mt. Edgecumbe microwave tower particularly so, given its proximity. This repeater station connects Rerewhakaaitu, Murupara and Galatea to the Telecom network, via the Manawahe station. Damage to this would leave these settlements without telecommunications until repairs could be made. Between Whakatane and Tauranga a fibre optic cable provides a physical link to the network, similarly Rotorua and Taupo are also linked with a fibre optic cable (Johnston, 1997). These cables should provide a more robust link during and after an eruption, though electrical disturbances during the presence of the ash cloud may still affect these connections.

The effects of ashfall on exchanges are potentially severe if tephra manages to penetrate exchange buildings. Both electrical and abrasive damage of equipment is possible. Rotorua, which may potentially receive more ash than either Whakatane or Tauranga, fortunately has a reasonably well-sealed building, maintaining a positive pressure inside. Charcoal air scrubbers on the bottom floor are designed to clean the outside air of gas, and are largely effective – though some corrosion from H_2S has occurred. Air conditioning units are also placed on the flat roof. All of these air-conditioning units and backup diesel generator air intakes have filters installed (Gordon, 2002). The survival of the air-conditioning is essential for two reasons. Firstly, without positive pressure inside the building, ash is much more likely to find its way inside, and interfere with electronic equipment. Secondly, the systems produce a great deal of heat, and need to be cooled to continue to operate. Overheating will result in systems shutting down within half an hour if air-conditioning systems are rendered inoperative. For this reason ash will need to be removed from intake filters or filters replaced quickly after an eruption. An 1886 type eruption will be over in a matter of hours, and therefore this essential maintenance should be easily completed.

In the event of power cuts, all exchanges have back-up batteries that will provide essential power for 4-8 hours, after which diesel generators will take over. Telecom service boxes around Rotorua have recently been upgraded with Invensys ™ air-conditioning units, as opposed to simple air vents. While the service boxes are otherwise sealed, the intakes for the air-conditioning units have no filters (Gordon, 2002). These will be susceptible to ash infiltration, which may in turn damage components, and cause localized disruptions to telephone connections.

The most catastrophic damage that may possibly occur would be the collapse of roofs on exchange buildings. While unlikely to happen in Whakatane or Tauranga, it is a possibility in Rotorua in the event of easterly winds during an eruption. This would destroy most equipment on the top floor, and all air-conditioning on the roof, which would in turn stop all equipment from working, closing the exchange down.

5.3 Agriculture and Forestry

The Bay of Plenty region is intensively farmed and commercially forested, with 312,420 hectares of land currently utilized in these ways. The Agricultural Production Survey for the year ended 30 June 1999 listed land use by Regional Council, giving the following results for the Bay of Plenty:

Table 5.5 Land use within the Bay of Plenty regional council boundaries, as of June 30 1999 (Source: Statistics NZ)

Grazing, Arable, Fodder and Fallow Land		Land in Horticulture		Plantations of Exotic Timber		Other land		Total Land	
Number of Farms	Area in Hectares	Number of Farms	Area in Hectares	Number of Farms	Area in Hectares	Number of Farms	Area in Hectares	Number of Farms	Area in Hectares
3,876	254, 548	525	2,595	690	13,564	975	41,434	4,020	312,140

The above figures on take into account land within the Bay of Plenty Regional Council (EBOP) boundaries (figure 5.11). Commercial forest plantations also cover a large area to the south of Rotorua, in Rotorua district but under the auspices of the Waikato Regional Council. The same survey lists 39,397 hectares of land as being used for plantations of exotic timber in Waikato (Statistics NZ). These figures indicate that there is a lot of productive land at risk from a basaltic eruption of Tarawera. Effects will differ depending on land use, ash thickness and in some cases what season it is.

Figure 5.11 Bay of Plenty Regional Council (EBOP) boundary

5.3.1 Horticulture and Agriculture

Even a few millimeters of ash have the capability to cause massive amounts of damage to crops, and potentially harm livestock. Depending on the thickness of the ash and the season, short-term effects could devastate the local agricultural industry. Although any season an eruption will cause major damage to agriculture and horticulture, at some times of the year damage will be exacerbated by the stage various crops are at. Any time between November and April will cause worse impacts than during the rest of the year. During these times annual crops will be ripening. Leafy crops such as cabbage, lettuce and broccoli will be ruined by even light ashfalls (Johnston, 1997). Pollination of flowering crops may not occur if thin layers of ash cover the flowers. The devastation of citrus production in the province of Catania by 1-3 mm ashfalls in the 2002 eruption of Etna illustrated how vulnerable crops are to ashfall, especially if affected during vulnerable stages of development (chapter 3). Table 5.6 indicates critical stages of development for various crop types.

Table 5.6 Periods of high crop risk from ash falls (from Johnston, 1997)

	September	October	November	December	January	February	March	April	May	June
Peas			End of flowering						Emergence	
Squash			Initial stages of growth and flowering							
Tomatoes					Flowering stages					
Sweetcorn			Early stages of growth							
Pipfruit		Blossom		After blossoming		Later stages of development				
Stonefruit	Blossom			Cosmetic effects						
Kiwifruit			Blossom					Harvest		
Grape		Flowering		Fruit development		Harvest				

Johnston & Nairn (1993) indicate crops and pastures under 50 mm of ash or more are not likely to survive tephra falls. However pastures have been shown to be able to recover in greater depths of ash than this. After the 1886 eruption plants buried at this depth or deeper than this began to quickly re-establish themselves. In many areas this happened by the next spring (3 months later). For example Te Puke, with 75 mm of tephra and Opouriau with 50 mm both had grass growing back through the ash in this short time (Keam, 1988). The same applied to Opotiki, though only 3 cm of ash was present here. Certainly 50 mm of tephra will bury pastures and kill many crops, but experience from 1886 indicates that the basaltic ash is fertile enough that plants may survive moderate burials, and pastures may recover even with tephra thicknesses of 75 mm. Recovery of pastures will be sped up if tephra is ploughed into the existing soil. The fertility of the soil is expected to improve, based on reports from 1886 (Keam, 1988), and observations from the surrounding area of Etna. Ploughing ash into soil will also help prevent its remobilization, however this is only possible with depths of ash up to 200 mm (Johnston, 1997).

The effects of even moderate ashfalls on livestock essentially amount to a sudden loss of feed, and possibly water supplies. Feed will need to be imported from outside the area to supplement available pasture if tephra deposits exceed 5 mm. Amounts over this will result in the need for all feed to be brought in from elsewhere, and/or stock may need to be transported away to unaffected areas.

The leaching of toxic substances into soils from the ash is also possible – Fluorosis is commonly responsible for the deaths of stock when a significant component of fluoride is present within volcanic ash. This has occurred in several Icelandic eruptions, and was responsible for the deaths of over 2000 grazing animals from the 11 October 1995 eruption of Ruapehu (Cronin et al., 2003). An immediate toxic dietary intake of F is >100 $\mu g\ g^{-1}$ for grazing animals, though they may become sick before this: Cattle can tolerate around 40 $\mu g\ F\ g^{-1}$, sheep up to 60 $\mu g\ F\ g^{-1}$. Ingestion of fluoride occurs directly as tephra is consumed along with grass - under normal winter conditions sheep ingest 260-275 g of soil per day, stock foraging for feed amongst ash are likely to take in even more (Cronin et al., 2003). A leachate analysis of ash collected from Mount Etna in November 2002 was conducted by the Institute of Geological and Nuclear Sciences to determine the possibility of fluoride within samples of ash from the 2002 eruption (Table 5.7).

Table 5.7 Leachate analysis of samples of Etna 2002 ash. Sample collection dates and distance from source are given

		25 km, 10/11/02	12 km, 07/11/02
Lithium	mg/g of dry ash	<0.0005	<0.0005
Sodium	mg/g of dry ash	0.189	0.111
Potassium	mg/g of dry ash	0.024	0.0
Calcium	mg/g of dry ash	0.073	0.152
Magnesium	mg/g of dry ash	0.0072	0.0072
Sulphate	mg/g of dry ash	0.38	0.46
Boron	mg/g of dry ash	0.0013	<0.001
Silica (as SiO2)	mg/g of dry ash	0.014	0.027
Nitrate (as N)	mg/g of dry ash	0.0016	<0.0015
Phosphate (as P)	mg/g of dry ash	<0.0025	<0.0025
Al	mg/g of dry ash	0.0072	0.0022
Arsenic	mg/g of dry ash	0.0082	0.006
Bromide	mg/g of dry ash	<0.005	<0.005
Chloride	mg/g of dry ash	0.097	0.077
Fluoride	mg/g of dry ash	0.05	0.025
Iron	mg/g of dry ash	<0.0002	0.0004

Amounts were generally low, however the sample collected in Catania on 10 November gave results of 50 $\mu g\ g^{-1}$. This is above the toxicity threshold for cattle. No reports of fluorosis have been given to date, but most of the land use around Etna is devoted to horticulture, with some sheep farming. Cattle are not common. No evidence of fluorosis occurring exists from the Tarawera 1886 eruption, but nevertheless it is a possibility that needs to be considered.

Long-term effects

Deeper deposits of ash will result in longer recovery times. The immediate vicinity of Tarawera and Rotomahana was completely devastated after the 1886 eruption. Nothing survived above 850 m (Clarkson & Clarkson, 1991) and only a few patches of vegetation survived below this on the southeast side of the mountain. The area to the west of Rotomahana was affected by base surges, which also killed and buried everything in their path. These deeply buried areas remained barren for about 10 years. Toetoe and tutu colonized near the shores of Lake Tarawera, and mat daisies began colonizing the middle slopes within 20 years. After 40 years forest was extending up the mountain from the lake edge – seeds were being spread by wind and birds (Clarkson & Clarkson, 1991). These areas that took time to recover were not infertile, there was simply too much tephra for plants that were buried to grow through, re-colonization was necessary. The high permeability of the tephra meant that little rilling or surface erosion took place after the eruption, and the ash largely remained in place (White et al., 1997). Plants were therefore not exposed by subsequent rains, and remained covered in ash. In the long-term a deposit of basaltic ash will be beneficial, as the mineralogy of the ash will improve soil fertility. Many farmers and market gardeners may however be ruined financially before they can reap the benefits of the improved soils.

5.3.2 Forestry

Ashfall alone is not likely to kill mature trees, but the accumulated weight of ash is likely to break large branches in proximal areas. Rees (1970) indicated that this is likely to occur with ashfall over 500 mm thickness. Over 1500 mm would kill all trees, under 500 mm would result in slight damage and partial survival of shrubs. These results were based on the Parícutin eruption of 1943-52. Eggler (1963, cited in Blong 1984) also studying the Parícutin eruption noted that pine trees with basal diameters from 100–300 mm had the best rates of survival. This was because the trunks/branches were strong enough to resist excessive bending, but flexible enough to dump part of the ash load. The 1886 Tarawera eruption also gives a good indication of likely damage to trees. Even at 8 km from the Rotomahana section of the fissure, trees in Te Wairoa were completely defoliated by the ash, lapilli and mud. Trees here had bark stripped off the east side (facing Rotomahana), even though they were 2 km beyond the extent of base surges (Keam, 1988). Partly buried trees such as kamahi and tawa quickly resprouted though, some even producing seed the next year (Clarkson & Clarkson, 1991). To the northwest of Tarawera the 500 mm ashfall isopach almost reaches Lake Tikitapu, 11 km from the fissure. Thicknesses here were estimated by surveyor Henry Roche to be about 45 cm (Keam, 1988). The effects of ashfall here were a little more severe than the "slight damage" description given by Rees (1970) for this depth of ash. Photographs show that all trees are completely defoliated, several have fallen or lost branches (figures 5.11 & 5.12). It should be noted however that fallen trees in this area are attributed not just to ashfall, but also to strong winds that were blowing that night.

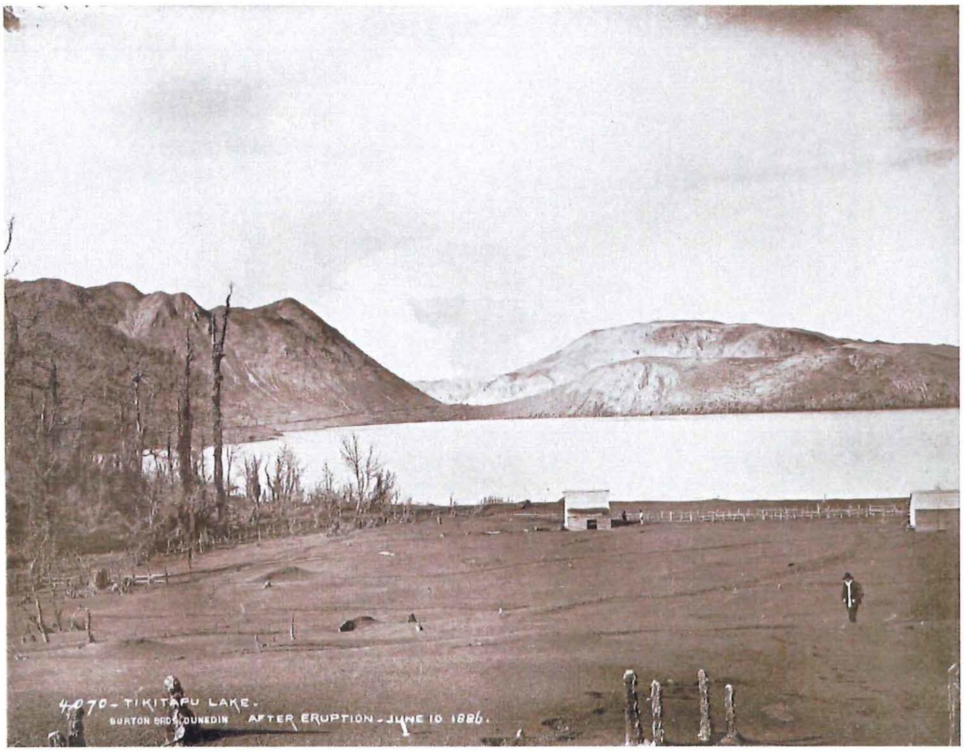


Figure 5.12, Tikitapu, 13 June, 1886 A. Ryan photograph

Figure 5.13 Tikitapu, July-September 1886 Burton Brothers photograph.
Note defoliated trees on the slope to the left of the lake

Downwind (northeast) of Tarawera on 10 June 1886, the 500 mm isopach fell approximately 12 km from source. This distance can therefore be taken as a likely maximum for a 500 mm isopach. Even though trees beyond this will be damaged, and defoliated for a few more kilometers, they will still be able to be harvested. (This will apply to some trees under this distance also). Beyond about 25 km (the maximum distance from source of the 300 mm isopach) trees may suffer some defoliation and branch breakages, but most will survive.

Even trees that are felled by the eruption may still be able to be harvested. 3000ha of trees belonging to the Weyerhaeuser Corporation were downed by pyroclastic flows from Mt. St Helens in 1980. Approximately 80% of these trees were still able to be salvaged (Blong, 1984). This should apply to forests in the Bay of Plenty region also, once access to those forests is gained after clearing roads. The age and therefore size and value of the trees will have a bearing on this. Saplings proximal to the volcano are likely to be destroyed by heavy ashfalls, or at least damaged enough that they are rendered worthless.

Replanting directly into the ash, or into soil covered in basaltic ash is expected to be successful. *Pinus Radiata*, which is widely grown in NZ, (including the Bay of Plenty) is successfully planted directly into basaltic ash on the slopes of Mt. Etna. Species of pine grow extremely well on Tarawera today, wilding pines such as *Pinus Nigra* and *Pinus Contorta* have spread over parts of Tarawera faster than many native plant communities (Clarkson & Clarkson, 1991). Growth through the 1886 tephra is exemplified by the fact that Poplar fence-posts in Te Wairoa that were buried in the ash have since grown into large poplar trees, and still stand amongst the “buried village” today.

5.4 Discussion

An eruption of the magnitude of the 1886 eruption could devastate the Bay of Plenty region, the amount of damage largely contingent upon wind direction. Although the likelihood of ashfall on Rotorua is low due to prevailing winds, the possibility of ashfall deposits totalling 30 cm thick exists. Many roofs will collapse, destroying houses, industry and the local economy. Roads will be essentially blocked to all but minimal 4wd traffic. No air traffic except helicopters would be able to land within the area. Line and substation failure would result in electricity cuts, in turn causing most water supplies and wastewater reticulation to fail. Similar effects could be had in Kawerau. Both of these centres may require evacuation of many residents, depending on the amount of damage. Some will have to be relocated due to their homes being destroyed. Those that stayed would need to be able to co-ordinate with civil defence to ensure basic living conditions could be maintained, e.g. having sufficient/safe shelter, food and water supplies.

Light ashfalls will result in temporary power cuts, airport closure in Rotorua, sewage treatment disruptions and some road closures. Seasonal crops may be damaged. Whakatane would not be subject to tephra fall as thick as is possible for Kawerau or Rotorua, but may experience electricity disruptions, sewage reticulation failures and will possibly run out of water. Leaving the region by road will be difficult until ash is cleared from SH 2 to Tauranga. Due to its distance from Tarawera Volcano, Tauranga is less vulnerable than Rotorua or Whakatane. Its water supply uses robust filtration methods, and diesel generators provide backup if power fails. Tephra loading damage is unlikely. In the event of easterly winds, power may be cut in the region of the Tarukenga substation. Tauranga's electricity supply is therefore its most vulnerable lifeline.

Chapter 6

Discussion

6.1 Thesis Objectives

The objectives of this thesis were:

- To identify possible hazards associated with a future basaltic eruption of Tarawera
- To determine probable effects of those hazards on the Bay of Plenty region, including the identification of vulnerable lifelines and infrastructure.

6.2 Conclusions

The likelihood of a future 1886 type eruption from Tarawera Volcano is unknown. The short geological history of Tarawera precludes a pattern of eruption types and frequency from being evident. However the fact that the 1886 eruption was not only the most recent basaltic eruption in Taupo Volcanic Zone, but the largest, indicates that future basaltic activity is definitely possible from this volcano. This possibility requires steps to be taken by local authorities to ensure that the risks associated with such a volcano are minimized. This thesis has sought to identify probable hazards and their potential effects as a step towards mitigating the hazards posed by basaltic volcanism at Tarawera Volcano.

In the event of an 1886 type eruption the Bay of Plenty region will be affected by a range of hazards types, including ashfall, bomb and lapilli fallout, phreatomagmatic eruptions and base surges, hydrothermal eruptions, lava flows, lahars, earthquakes, seiching and poisonous gases. These processes will devastate parts of the Bay of Plenty region. How much damage is done will in part be determined by wind direction, as this will govern which distal areas are affected.

Proximal areas

Much of the immediate area around Lake Rotomahana / Waimangu will be completely destroyed by base surges. Phreatomagmatic explosions arising from the interaction of magma and the groundwater of the Rotomahana-Waimangu geothermal system will create both primary surges from lateral blasts, and secondary pyroclastic surges from the collapse of unstable eruption columns. As well as completely destroying houses, farms, forests and several minor roads, these surges are also likely to reach State Highway 5, south of Waimangu, cutting off the main Rotorua-Taupo link. The 220kV transmission lines which represent one of two main electrical links for the Bay of Plenty to the rest of New Zealand also fall within the hazard zone posed by base surges.

All areas within 20 km of the volcano will be subject to lapilli up to 32 mm, causing minor damage to property and possibly causing some injury. 64 mm clasts may travel up to 12 km, and will have enough impact energy to break windows, roof tiles and to damage iron roofs. The risk of severe injuries and fatalities will be posed to people and livestock. Larger bombs up to 128 mm may be thrown as far as 6 km. These will create more damage, possibly even penetrating iron roofs.

The hazards posed by lava flows will pose little threat to infrastructure or lifelines, as the area affected by them consist largely of forests. Fires started by the flows pose more danger as they have the potential to spread far beyond the limits of the lava flows themselves.

Proximal areas will also be subject to thick tephra accumulations, killing trees, collapsing buildings and burying roads. The Spencer Road community is extremely vulnerable to this, due to its proximity. The only closer communities are Rerewhakaaitu and houses in the Rotomahana area. While also vulnerable they face more of a threat from base surges.

Medial areas

Kawerau and Rotorua may be affected by up to 30 cm thick ashfall deposits. The likelihood of this much ash falling on Rotorua is low due to prevailing winds being westerly, but it is a possibility. Effects will include the collapse of roofs and possibly entire structures, especially of commercial and industrial buildings with large-span, low-pitch or flat roofs. Power lines may be brought down by tephra loading, electrical flashovers will occur on substation and transmission line insulators, especially on low voltage lines. Ensuing power cuts will in turn cause most water supplies and wastewater reticulation to fail. Roads will be blocked to all but minimal 4wd traffic. Steep hills will be impassable to all vehicles until roads have been cleared with heavy earthmoving equipment. This thickness of tephra may result in the evacuation of many residents, depending on the amount of damage sustained. Some will have to be relocated due to their homes being destroyed.

In the event of light (< 5 cm) of ashfall, effects will still be considerable. The airport at Rotorua will be closed, as will many roads. Temporary power cuts may occur, causing water shortages and sewage reticulation failure. Seasonal crops will sustain heavy losses, but long-term fertility of soils is expected to be improved. Stormwater drainage systems may be inundated by large amounts of tephra and subsequently blocked, resulting in localized flooding during even moderate rain.

Hazards affecting Rotorua and Kawerau that are not contingent upon wind direction include minor earthquakes not expected to be larger than MM V. In Rotorua, possible gas bursts of CO_2 and H_2S may occur as a result of tremors. Such gas releases will asphyxiate people in enclosed rooms or in extreme proximity to the source of these gases. Rotorua may also experience hazardous hydrothermal eruptions in its geothermally active area. These areas include not only parks, but the CBD and a few residential zones.

Distal areas

The maximum amount of ashfall expected in Whakatane is ~ 7.5 cm, the same amount as it received in 1886. Whakatane's most vulnerable lifeline is its water supply, it currently has no back-up generator if electricity fails, and its water is derived from the Tarawera river, which may be subject to lahars and/or high sediment loads. Reservoirs in Whakatane hold less water than is usually used in any 24-hour period. Sewage reticulation is also dependant on electricity, which again is vulnerable to cuts. This is possible both from local substation damage at Edgecumbe and Tarukenga, and from disruptions to main transmission lines south of Waimangu. The integrity of these lines is necessary for the entire Bay of Plenty region to connect to the national grid. Some back-up power may be available from the Matahina and Aniwhenua hydro stations, assuming Edgecumbe station survives. The electricity supply is the most vulnerable of Tauranga's lifelines, it is included in the region depending on the Tarukenga substation. Otherwise it is distal enough that the light ashfalls possible will be of nuisance value rather than hazardous.

Distal roading will be affected, especially for Whakatane. Even ash deposits of 1 mm will create traction and visibility problems, causing accidents and slowing traffic. Thicker deposits will close roads to all but essential traffic, and in some cases will only be passable by 4wd vehicles. Connecting to any main centre from Whakatane will involve driving closer to Tarawera, and thus into thicker tephra deposits. Leaving the region by road will be difficult until ash is cleared from SH 2 to Tauranga.

6.3 Recommendations

The most vulnerable communities are of course those closest to the volcano. However mitigating effects of some hazards is not possible; Rotomahana and Rerewhakaaitu settlements are both in danger of destruction from base surges, yet little could be done to alleviate these effects. Evacuation is the only option available. However evacuation may not always be possible in some areas. Spencer Road is also close enough that complete destruction of houses and the lifelines serving this community is a possibility. An evacuation of this community would save many lives, however should an eruption start before this had taken place, the sole evacuation route could very easily be cut off. The northern part of the community around Te Karamea Bay is 2 km further from the volcano than the closest part of the road at Ohinetekura point. At this proximity getting 2 km closer to the volcano would be extremely dangerous, and may not be possible. Building a suitable vehicle track or road to connect Spencer Road with Millar Road (see figure 4.6) would provide an emergency evacuation route. Only 2 km separates these roads, therefore only a small amount of money would be required to create an access route that will potentially save hundreds of lives.

Whakatane has a water supply that is particularly vulnerable to volcanic hazards. This is partly due to its source from the Whakatane river, which may be subject to lahars and/or high turbidity levels after an eruption. Current treatment methods will not cope with a large sediment influx; further settling tanks are required. While one has been proposed to be emplaced within 5-6 years, this needs to be prioritized. Whakatane does not have a large reservoir capacity, so stored water will not last for even 24 hours under normal usage. It is therefore important that treatment does not fail. Increasing the number or capacity of reservoirs would also help to reduce the risks posed by an eruption.

Electrical weather sheds on insulators in areas proximal to Tarawera could be made larger to reduce the risk of flashovers cause by the adherence of wet volcanic ash. Thus the risk of power failures would be reduced.

Currently only a few houses and farms exist in close proximity to Rotomahana. Recent trends towards the creation of "lifestyle blocks" in New Zealand have included areas such as the eastern shore of Lake Rotorua. Should this type of development occur here, the vulnerability of the area would increase as more property was put at risk. No mitigation can be effected against pyroclastic surges, it is therefore strongly recommended that the district and regional councils oppose residential development in this area.

During a period of precursory activity, several steps could be taken mitigate possible effects of an eruption. These include:

- Relocating earthmoving and road maintenance equipment away from depots near Tarawera, such as the Rotorua depot, would prevent them from being buried in deep tephra deposits. They would then be available to be used in re-opening roads into affected areas.
- Stockpiling of electrical cables by power companies to replace downed transmission lines would lessen the time taken to re-establish electrical distribution networks after the cessation of the eruption.
- The closure of geothermal parks such as Kuirau Park, Waiotapu and Whakawerawera during periods of increased activity may save lives, as unpredictable hydrothermal eruptions may occur in these areas.

- Evacuation route plans for proximal areas should be distributed by Civil Defense, as should information on likely expected hazards (keeping in mind panicking the population needs to be avoided).
- Some spoutings and gutterings are easily removed from houses, simply unclipping from brackets. These could be temporarily removed to protect them from damage from ash accumulations

6.4 Future Research

During the course of writing this thesis it has become apparent that there are several areas relating to the effects of volcanism in New Zealand that require future research. A short list of the most important topics needing attention is listed below:

- The effects of tephra loading on New Zealand structures is currently based on comparisons with overseas tephra loading effects, and on the use of a generalized specification of roof loading capabilities of 2.5 kPa. A more precise determination of actual roof loading capabilities for different types of structures in New Zealand would further constrain probable effects of tephra loading.

- The environmental impacts of large quantities of ash being disposed of into the ocean have not been studied. While dumping ash off shore may be more expensive than disposal on land, there may not be enough sites on land where large amounts of ash may be accommodated. Additional marine impacts may be minimal in the event of large quantities of ash already present from fallout and river discharge. This hypothesis needs to be tested though. A possible study area is the east coast of Sicily, where tephra has been disposed of into marine environments already affected by ashfall.

- The recovery of the region after an 1886 type basaltic volcanic eruption was outside the scope of this thesis. The impacts of a 30 cm deposit of ash on the population of Rotorua would be enormous. The evacuation of a large proportion of the city would be necessary, and the rehabilitation of the area (where possible) would require a lot of time and money. The local, regional and national economies would be severely affected. Research into the social impacts and recovery of the region after such an event needs to be conducted, including planning for re-zoning of land-use after the event. Possible outcomes of this research may indicate which areas may be feasibly rehabilitated, and which areas may not be economically viable to recover.

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Appendix 1

The Modified Mercalli Intensity Scale (after Dowrick, 1996).

MM 1	Not felt except by a very few people under exceptionally favourable circumstances
MM 2	Felt by persons at rest, on upper floors or favourably placed
MM 3	Felt indoors; hanging objects may swing, vibration similar to passing of light trucks, duration may be estimated, may not be recognised as an earthquake.
MM 4	Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to the passing of a heavy traffic, or to the jolt of a heavy object falling or striking the building. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock. Walls and frame of buildings, and partitions and suspended ceilings in commercial buildings, may be heard to creak.
MM 5	Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Hanging pictures knock against the wall. Open doors may swing. Cupboard doors secured by magnetic catches may open. Pendulum clocks stop, start, or change rate. Some windows Type I cracked. A few earthenware toilet fixtures cracked.
MM 6	Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Objects fall from shelves, pictures fall from walls. Some furniture moved on smooth floors, some free-standing unsecured fireplaces moved. Glassware and crockery broken, very unstable furniture overturned. Small church and school bells ring. Appliances move on bench and table tops. Filing cabinets or 'easy glide' drawers may open [or shut]. Slight damage to Buildings Type I. Some stucco or cement plaster falls. Windows Type I broken. Damage to a few weak domestic chimneys, some may fall. Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from sloping ground, e.g. existing slides, talus slopes, shingle slides.
MM 7	General alarm, difficulty experienced in standing. Noticed by motorcar drivers who may stop. Large bells ring, furniture moves on smooth floors, may move on carpeted floors. Substantial damage to fragile contents of buildings. Unreinforced stone and brick walls cracked. Buildings Type I cracked with some minor masonry falls. A few instances of damage to Buildings Type II. Unbraced parapets, unbraced brick gables, and architectural ornaments fall. Roofing tiles, especially ridge tiles may be dislodged. Many unreinforced domestic chimneys damaged, often falling from the roof-line. Water tanks Type I burst. A few instances of damage to brick veneers and plaster or cement-based linings. Unrestrained water cylinders [Water Tanks Type II] may move and leak. Some windows Type II cracked. Suspended ceilings damaged. Water made turbid by stirred up mud. Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings. Instances of settlement of unconsolidated or wet, or weak soils. Some fine cracks appear in sloping ground. A few instances of liquefaction [i.e. small water and sand ejections].

MM 8	Alarm may approach panic. Steering of motor cars greatly affected. Building Type I, heavily damaged, some collapse. Buildings Type II damaged, some with partial collapse. Buildings Type III damaged in some cases. A few instances of damage to Structures Type IV. Monuments and pre-1976 elevated tanks and factory stacks twisted or brought down, some pre-1965 infill masonry panels damaged, a few post-1980 brick veneers damaged, decayed timber piles of houses damaged, houses not secured to foundations may move. Most unreinforced domestic chimneys are damaged, some below roof-line, many brought down. Cracks appear on steep slopes and in wet ground, small to moderate slides occur in roadside cuttings and unsupported excavations, small water and sand ejections and localised lateral spreading adjacent to streams, canals, lakes etc.
MM 9	Many Buildings Type I destroyed. Buildings Type II heavily damaged, some collapse. Buildings Type III damaged, some with partial collapse Structures Type IV damaged in some cases. Some with flexible frames seriously damaged. Damage or permanent distortion to some Structures Type V. Houses not secured to foundations shifted off. Brick veneers fall and expose frames. Cracking of ground conspicuous, landsliding general on steep slopes. Liquefaction effects intensified and more widespread, with large lateral spreading and flow sliding adjacent to streams, canals, lakes etc.
MM 10	Most Buildings Type I destroyed. Many Buildings Type II destroyed Buildings Type III heavily damaged, some collapse. Structures Type IV damaged, some with partial collapse. Structures Type V moderately damaged, but with few partial collapses. A few instances of damage to Structures Type VI. Some well-built timber buildings moderately damaged (excluding damage from falling chimneys). Landsliding very widespread in susceptible terrain, with very large rock masses displaced on steep slopes. Landslide dams may be formed. Liquefaction effects widespread and severe
MM 11	Most Buildings Type II destroyed. Many Buildings Type III destroyed Structures Type IV heavily damaged, some collapse. Structures Type V damaged, some with partial collapse. Structures Type VI suffer minor damage, a few moderately damaged.
MM 12	Most Buildings Type III destroyed. Many Structures Type IV destroyed Structure Type V heavily damaged, some with partial collapse Structures Type VI moderately damaged.

<u>Construction types</u>

Buildings Type I [Masonry D in NZ 1965 MM Scale]

Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick or rammed earth. Soft storey structures [e.g. shops] made of masonry, weak reinforced concrete, or composite materials [e.g. some walls timber, some brick] not well tied together. Masonry Buildings otherwise conforming to Building Types I-III, but also having heavy unreinforced masonry towers. [Buildings constructed entirely of timber must be of extremely low quality to be Type I].

Buildings Type II [Masonry C in the NZ 1966 MM Scale]

Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces. Such buildings not having heavy unreinforced masonry towers.

Buildings Type III [Masonry B in the NZ 1966 MM Scale]

Reinforced masonry or concrete buildings of good workmanship and with sound mortar, but not formally designed to resist earthquake forces.

Structures Type IV [Masonry A in the NZ 1966 MM Scale]

Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special collapse or damage limiting measures taken [mid-1930s to c1970 for concrete and to c1980 for other materials].

Structures Type V

Buildings and bridges, designed and built to normal use standards, i.e. no special damage limiting measures taken, other than code requirements, dating from since c1970 for concrete and c1980 for other materials.

Structure Type VI

Structures dating from c1980, with well-defined foundation behaviour, which have been specially designed for minimal damage, e.g. seismically isolated emergency facilities, some structures with dangerous or high contents, or new generation low damage structures.

Windows

Type I – Large display windows, especially shop windows.
Type II – Ordinary sash or casement windows

Water Tanks

Type I – External, stand-mounted, corrugated iron water tanks
Type II – Domestic hot-water cylinders unrestrained except by supply and delivery pipes.

Available from (http://www.es.mq.edu.au/NHRC/web/scales/scalespage2.htm)

Appendix 2

European Macroseismic Scale and Scientific Alert Level description.

EMS	DEFINITION	DESCRIPTION
1	Not felt	Not felt, even under the most favourable circumstances.
2	Scarcely felt	Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.
3	Weak	The vibration is weak and is felt indoors by a few people. People at rest feel a swaying or light trembling.
4	Largely observed	The earthquake is felt indoors by many people, outdoors by very few. A few people are awakened. The level of vibration is not frightening. Windows, doors and dishes rattle. Hanging objects swing.
5	Strong	The earthquake is felt indoors by most, outdoors by few. Many sleeping people awake. A few run outdoors. Buildings tremble throughout. Hanging objects swing considerably. China and glasses clatter together. The vibration is strong. Top heavy objects topple over. Doors and windows swing open or shut.
6	Slightly damaging	Felt by most indoors and by many outdoors. Many people in buildings are frightened and run outdoors. Small objects fall. Slight damage to many ordinary buildings e.g.; fine cracks in plaster and small pieces of plaster fall.
7	Damaging	Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many ordinary buildings suffer moderate damage: small cracks in walls; partial collapse of chimneys.
8	Heavily damaging	Furniture may be overturned. Many ordinary buildings suffer damage: chimneys fall; large cracks appear in walls and a few buildings may partially collapse.
9	Destructive	Monuments and columns fall or are twisted. Many ordinary buildings partially collapse and a few collapse completely.
10	Very destructive	Many ordinary buildings collapse.
11	Devastating	Most ordinary buildings collapse.
12	Completely devastating	Practically all structures above and below ground are heavily damaged or destroyed.

Available from http://www.earthquakes.bgs.ac.uk/hazard/ems1.htm

Appendix 3

Scientific Alert Level	Indicative Phenomena	Volcano Status
0	Typical background surface activity; seismicity, deformation and heat flow at low levels.	Usual dormant, or quiescent state.
1	Apparent seismic, geodetic, thermal or other unrest indicators.	Initial signs of possible volcano unrest. No eruption threat.
2	Increase in number or intensity of unrest indicators (seismicity, deformation, heat flow etc).	Confirmation of volcano unrest. Eruption threat.
3	Minor steam eruptions. High-increasing trends of unrest indicators, significant effects on volcano, possibly beyond.	Minor eruptions commenced. Real possibility of hazardous eruptions.
4	Eruption of new magma. Sustained high levels of unrest indicators, significant effects beyond volcano.	Hazardous local eruption in progress. Large scale eruption now possible.
5	Destruction with major damage beyond active volcano. Significant risk over wider areas	Large hazardous volcanic eruption in progress.

Available from http://www.gns.cri.nz